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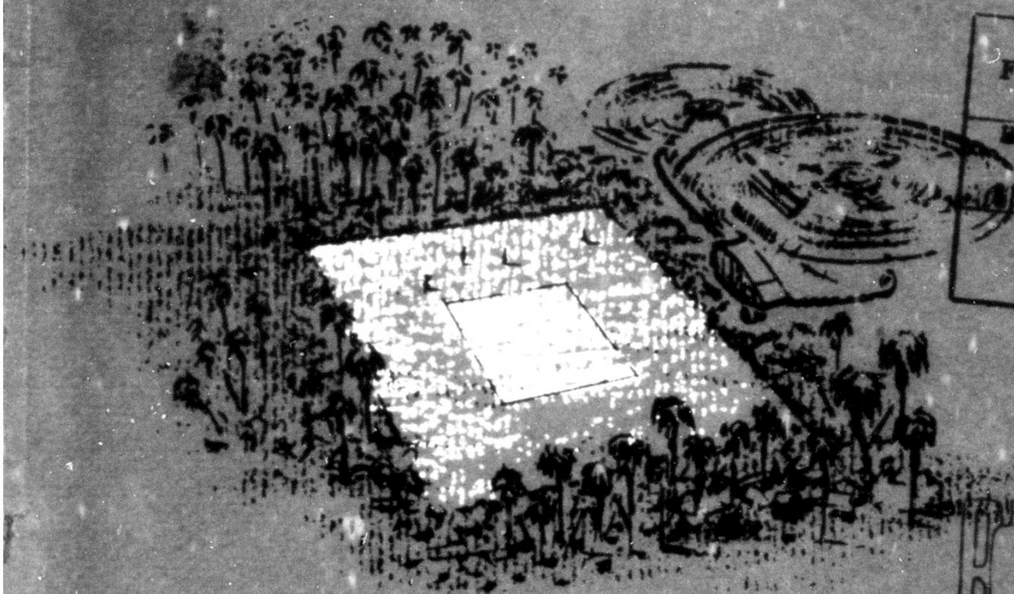
FEASIBILITY STUDY OF ON-SITE FABRICATED HELICOPTER PADS



PREPARED FOR THE MARINE CORPS LANDING FORCE DEVELOPMENT CENTER, QUANTICO, VIRGINIA, CONTRACT NUMBER NOm-73258.

D6-57117
November 1965

BOEING
AIRPLANE GROUP • PRODUCT DEVELOPMENT

SUPPORT SYSTEMS

PURPOSE

This document has been prepared to report the results of investigations into a feasibility study of on-site fabricated helicopter pads. These investigations were performed by The Boeing Company, Airplane Group, Product Development organization during the period May through September 1965.

The General Operational Requirement (Ref. 1, Sect. 3) states the Marine Corps requirement for improved helicopter pads, and the Project Directive (Ref. 2, Sect. 3) authorizes the investigation and evaluation of any material which shows promise of improved helicopter pads. These investigations were conducted for the Marine Corps Landing Force Development Center, Quantico, Virginia, under Contract NOm-73258.

For results of a similar feasibility study of on-site fabricated beach matting, performed concurrently under the same contract, refer to Boeing Document D6-57118.

INTRODUCTION

The objective of this study was to investigate the feasibility of rapid on-site fabrication of helicopter pads.

Lightweight, easy-to-apply, rapid-curing materials were evaluated through small- and large-scale laboratory testing conducted from May through September 1965. In addition, various application equipment was reviewed during this program. Experience gained by Boeing during research of materials and techniques for the rapid preparation of austere sites for aircraft was applied to this study. Coordination of this program was accomplished with Captain J. R. Rasavage, Combat Service Support Division, Marine Corps Landing Force Development Center, Quantico, Virginia. Results obtained during this program were also used in the beach matting feasibility study conducted as part of this investigation.

The Boeing Company Program Manager was L. A. Fleishman, J. P. Wirz was the Program Leader, and J. G. McEwan was the Principal Investigator, all from the Support Equipment/Facilities Unit, Support Systems. Material investigation and evaluation was conducted by M. C. Locke and W. S. Perkowski of the Material Technology Staff.

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1.0 SUMMARY

1.1 PROBLEM

The operation of helicopters on unprepared sites has proved to be a problem because of the ground erosion created by the rotor downwash. When hovering at low altitude over dry sand or loose dirt, helicopters pilots usually find themselves flying blindly in a dust cloud. Operations in sandy environment have shown that sand ingested by the engines and the action of the flying particles on the rotor greatly reduce the life of engine and rotor components. Such operations generate dust clouds during landing and takeoffs which reveal the presence and location of the aircraft to the enemy.

Currently, prefabricated plastic membranes are being evaluated by the Army and Marine Corps as a possible solution to this problem. Although the plastic membranes are effective in preventing ground erosion, some problems have been encountered during field installations. Considerable troop effort is required for installation and maintenance of the membrane helicopter pads.

A method for providing rapid on-site fabrication of helicopter pads bonded with the soil would solve the foreign object damage (FOD) problems of helicopter operations on sand or loose dirt and permit more effective dispersal of helicopters, while minimizing helicopter pad construction equipment and personnel requirements.

1.2 APPROACH

The on-site fabrication of helicopter pads using plastic resins and other lightweight materials was investigated. It was assumed that rapid curing materials could be sprayed or poured over soil, resulting in a surfacing of sufficient strength to allow the operation of helicopters on low California Bearing Ratio (CBR) soils. Materials were sought which had desirable characteristics such as rapid curing under wide temperature and moisture conditions, low cost, low toxicity, high strength-to-weight ratio, easy application, and extended storage life. The materials search and testing which constituted this feasibility study were accomplished as follows.

1.2.1 PHASE I ANALYSES AND MATERIALS INVESTIGATION

A review of potential materials was performed. An in-house material review and an industry-wide search for potential materials were conducted to ensure that the latest material development was reflected in the study.

1.2.2 PHASE II CONCEPTS INVESTIGATIONS

Combinations of materials and application concepts were investigated. Single-component materials as well as systems comprised of multiple elements were evaluated.

1.2.3 PHASE III LABORATORY TESTING

A laboratory testing program was conducted to efficiently screen a large number of materials. Cure rate and strength under adverse temperature and/or moisture conditions were the most significant characteristics under evaluation during this phase. Samples of materials exhibiting the best potential were prepared for wheel load testing.

1.2.4 PHASE IV APPLICATION EQUIPMENT REVIEW

Commercially available application equipment that could be adapted to military use was reviewed and evaluated. In addition, Marine Corps vehicles suitable for transportation of application equipment were reviewed.

1.3 FINDINGS

1.3.1 MATERIAL EVALUATION

Forty-three materials were evaluated. Materials which did not cure within a prescribed 3-hour limit were eliminated from further structural testing. Twenty materials were subjected to small-scale structural testing. Of these materials, three polyester resins, one epoxy resin, and one polyurethane foam exhibited the highest strength characteristics.

Various specimens of the above five materials were prepared for wheel load testing. To improve the strength-to-weight ratio and to optimize cure time, thereby eliminating cure cracks, chopped fiberglass was added to the polyester and epoxy specimens.

Static wheel-load tests of 14,000 pounds and 80 psi tire pressure were performed, simulating the CH-37C marine helicopter wheel loading. The CH-46A (6200 pounds at 150 psi) and the CH-53A (7960 pounds at 95 psi), both on dual wheels, are considered to have less severe wheel loading characteristics. The tests were performed on 3 by 5 foot specimens and the following results were obtained:

a. All polyester reinforced with 17 to 35 percent chopped fiberglass withstood the 14,000 pound wheel load. These specimens required approximately 2 pounds per square foot of surfacing material.

b. One epoxy specimen reinforced with 19 percent chopped fiberglass withstood a 10,000 pound wheel load. This specimen required approximately 1.2 pounds per square foot of surfacing material. Another fiberglass reinforced epoxy specimen with 32 percent chopped fiberglass withstood the 14,000 pound wheel load. This specimen required approximately 2 pounds per square foot of surfacing material.

c. One polyurethane foam specimen with an 18 pound per cubic foot density and an average thickness of 1 inch failed at a 3700 pound wheel loading.

1.3.2 APPLICATION EQUIPMENT REVIEW

Epoxy and polyurethane foam require application equipment where the catalyst and resin are mixed within the spray gun. External-mixing application equipment was found to be the most simple and dependable for spraying reinforced polyester resins. In addition, usage of low pressure, external mixing equipment eliminates the requirement for manual rollout of entrapped air from the surfacing material.

When helicopter pads are to be prepared on a permanent location, the Marine Corps TD-15 tractor was considered to be most acceptable for on-site helicopter pad fabrication on low CBR soil. Important factors in favor of this vehicle were light load bearing tracks, adequate weight carrying capacity, availability of auxiliary power, constant-speed performance over varying ground, and good grading capability. The M51 dump truck was considered a good alternate vehicle for pad fabrication on high CBR soils where grading is not required. Important factors in favor of this truck were adequate weight-carrying capacity, availability of auxiliary power, and constant low speed performance. The M35 2 1/2 ton truck was considered adequate for transportation of material and manually operated application equipment.

For the preparation of helicopter pads in remote locations, the M37 truck and the M105 trailer were selected. These vehicles not only accommodate material and application equipment, but are air transportable in the CH-37C and CH-53A helicopters.

1.4 CONCLUSIONS

Based on the results obtained during this study, on-site fabrication of helicopter pads is considered feasible.

Within the current state of the art, reinforced polyesters possess the required curing and strength characteristics. It is possible to adjust the curing characteristics of the compound at various ambient temperatures by changing the amount of promoter. This versatility and the low-cost raw materials establish the polyesters as having the best potential for helicopter pad preparation. Results obtained during wheel load testing of reinforced polyester specimens indicate that 2 pounds per square foot of surfacing material will have to be applied for the preparation of helicopter pads over uncompacted sand (Cone Index 30, at 6 inch depth; CBR less than one). This thickness can be decreased as the CBR of the soil increases. Although epoxy resins and polyurethane foams show promise, the curing problems under moisture conditions and the need for more complex spraying equipment make these compounds appear to be less suitable than polyesters. However, the rapid curing characteristics and high strength-to-weight ratio of polyurethane foams offer good potential for surfacing application if simplified application methods can be developed.

1.5 RECOMMENDATIONS

In view of the results obtained during this program, the following is recommended:

a. Using modified commercial application equipment, prepare operational size test pads of reinforced polyester so that resistance to aircraft operations, weatherability, repairability, and general suitability to field environment of the material can be determined.

b. Continue the survey and evaluation of new developments in the material and application equipment field.

c. Design, build, and test field application equipment for rapid preparation of helicopter pads with reinforced polyester.

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2.0 DISCUSSION

2.1 BACKGROUND

During heli-borne operations, helicopters are used extensively to rapidly transport troops and equipment to and from strategic locations. Such helicopter missions require operation on unprepared sites resulting in operational problems when landings and takeoffs must be accomplished in sandy or dusty environment.

During a recent landing exercise, "Quick Kick VII" at Vieques Island (Puerto Rico), Marine helicopters encountered the difficult task of operating in dusty environment.

2.1.1 PROBLEMS

As demonstrated during the recent military exercise "Quick Kick VII", helicopters operating on unprepared sites created a dust cloud that was visible from several miles. Even helicopters operating from asphalt strips as shown in Fig. 1 were blowing dust from the adjacent areas. Under these conditions, helicopter breakdowns were experienced and several aircraft were out of service before the end of the exercise.

2.1.2 CURRENT PADS

Currently, prefabricated vinyl-nylon membranes are being evaluated for helicopter pads. These membranes are placed over the ground and anchored. Ditching, back filling, and compacting around the periphery of the membrane are required to secure the pad and military personnel are required

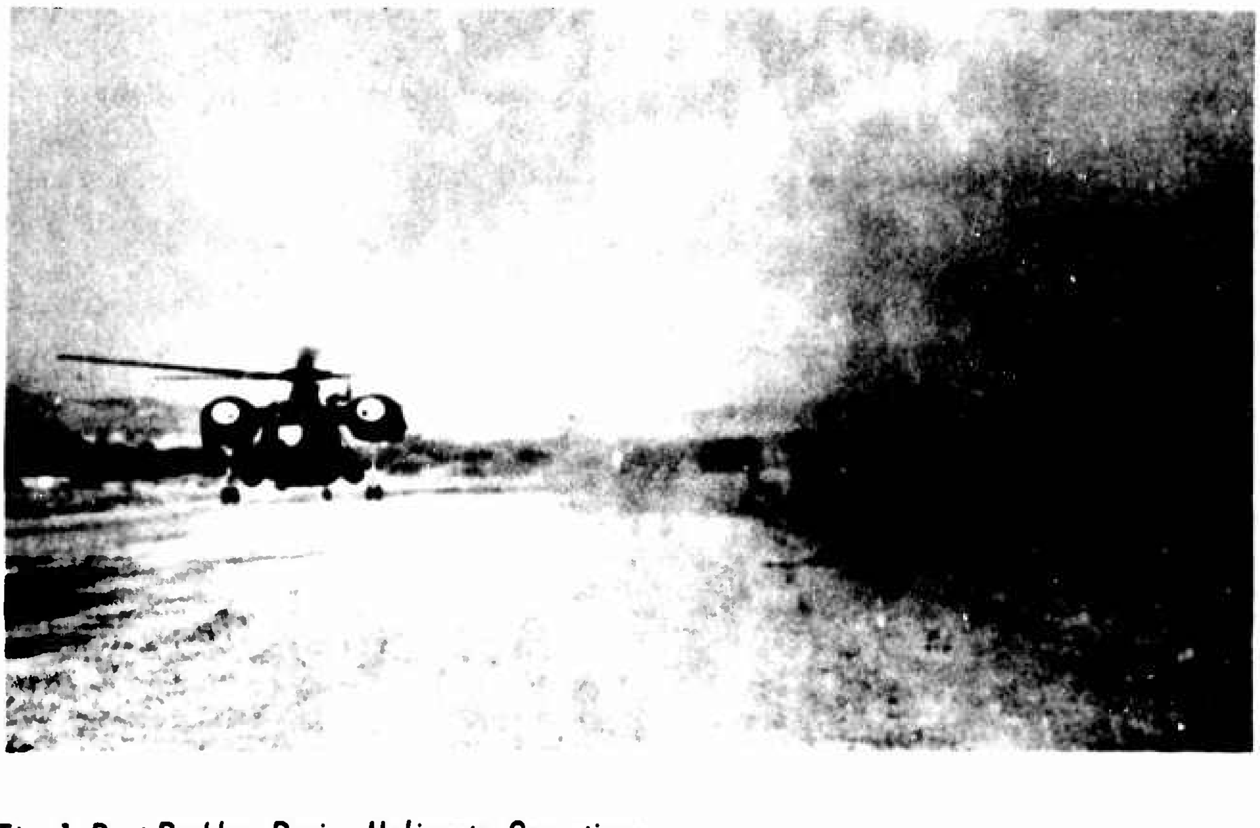


Fig. 1 Dust Problem During Helicopter Operations

for the placement. Several installation and operational problems are encountered with this type of helicopter pad as indicated in Ref. 3, Sect. 3.

2.2 ANALYSES AND MATERIALS INVESTIGATIONS

It was assumed that rapid curing materials could be sprayed or poured over the soil, providing a soil surfacing that would withstand helicopter wheel loads and rotor downwash. An industry-wide search for applicable materials and a review of materials previously evaluated during recent company-funded studies was performed.

2.2.1 CRITERIA

Readily available materials were sought having the characteristics described in the following paragraphs.

2.2.1.1 Curing

The material should cure under any environmental condition of temperature and moisture and on various soils. A 3-hour cure limit was mutually agreed upon between Boeing and the Marine Corps Project Officer as the maximum acceptable time.

2.2.1.2 Strength and Trafficability

The material should possess sufficient strength so that lightweight coverage will provide adequate pavement and resistance to repeated aircraft operations. The maximum wheel load that will be imposed on the pad is 13,600 pounds with an 82 psi tire inflation pressure for the CH-37C.

2.2.1.3 Transportation

The material should be transportable in convenient containers and require no special handling equipment.

2.2.1.4 Storage

The material should have an extended shelf life at extreme environmental temperatures.

2.2.1.5 Cost

The material should be of low cost when obtained in large quantities.

2.2.1.6 Material Restrictions

The material should be non-critical, non-corrosive, non-flammable, non-toxic, and be of a color that is compatible with current camouflage practices.

2.2.1.7 Application

The material should be capable of being readily applied with minimal equipment and skilled personnel.

2.2.1.8 Repairability

The material should be easily repairable under field conditions.

2.2.1.9 Weight

Surfacing material should not exceed 2.5 pounds per square foot.

2.2.2 MATERIAL SEARCH

From a list of potential suppliers, a letter explaining the purpose of the feasibility study along with the basic material requirements was sent to all potential manufacturers. Industries contacted included manufacturers of epoxy, polyester, silicone, urethane, synthetic rubber, grout materials, and soil stabilizers. Materials information, brochures, and samples applicable to this program were requested. As a general rule, good cooperation was displayed by the manufacturers contacted.

2.2.3 FINDINGS

The in-house material review yielded the potential materials listed in Fig. 2. As a result of the industry search, literature on materials and/or samples (shown in Fig. 3) were received.

IN-HOUSE MATERIAL SEARCH	
MANUFACTURER	MATERIAL
AMERICAN CYANAMID	LAMINAC 184-5 LAMINAC 4128 LAMINAC 4128-7 LAMINAC EPX 154-2 CYAQUA 405-20 BEETLE RESIN
AMERICAN LATEX	STAFOAM AA622 STAFOAM AA1802 STAFOAM AA402 STAFOAM 3102 STAFOAM 302-92-18 STAFOAM 302-92-4
UPJOHN CO.	PAPI FOAM
GACO WESTERN CO.	HYPALON
GENERAL TIRE & RUBBER CO.	STYRENE BUTADIENE 67
HOOKER CHEMICAL	HETRON 92
ISOCHEM RESINS	ISOCHEMCLAD 175
MINESOTA MINING AND MANUFACTURING	EC 1000 EC 1034
ROHM & HAAS	P-43
SHELL CHEMICAL	EPON 812 & 815
THIOKOL	DUST ALLEVIATION POLYMER, E 23226 FT BASE

Fig. 2 In-House Material Search

MANUFACTURER	BROCHURES	SAMPLES
ARMOUR INDUSTRIAL CHEMICAL COMPANY	BULLETIN G22-R4 ON EMULSIFIERS	RECEIVED EMULSIFIER 1
ADHESIVE ENGINEERING COMPANY	CONCRESIVE 1201 CONCRESIVE 1203 CONCRESIVE 1202 CONCRESIVE 1204	INFORMATION RECEIVED TOO LATE FOR SAMPLE REQUEST
ARCHER DANIELS MIDLAND COMPANY	BULLETIN FOR EP 8726-11-2050-48 AND 48C CHEM REZ A200 LINO-KURE	AROPOL 7431-16, AROTHANE 156, CHEM REZ A200, LINO-CURE, EP 8726-11-2050-48
ALLIED CHEMICAL CORPORATION	-	"PLASKON" PE-382 POLYESTER, PL-25 PROMOTER, CUMENE HYDROPEROXIDE CATALYST 2
AMERICAN CYANAMID COMPANY	DATA SHEETS ON 4128 POLYESTER	-
AMERICAN SYNTHETIC RUBBER COMPANY	BULLETIN ON FLASBRENE	FLASBRENE 25VLV, FLASBRENE 25HV 3
AMOCO CHEMICAL CORPORATION	INSTRUCTION SHEET	POLYESTER SAMPLE
DATA DYNAMICS INDUSTRIAL CORPORATION	-	FLOROK
DESOTO CHEMICAL COATINGS, INC.	-	• 810-004 POLYESTER
E.F. HOUGHTON & CO.	-	EMULSION
FLEXIBLE PRODUCTS COMPANY	DATA SHEET ON URETHANE FOAM SYSTEMS • 9022 8013-6	REQUESTED BUT NOT RECEIVED
HERCULES POWDER COMPANY	VINSOL PHENOLIC RESIN BINDERS	VINSOL RESIN 4
HYSOL CORPORATION	GENERAL BROCHURE	HYSOL XCU-A123 URETHANE
MOBIL OIL COMPANY	DATA SHEET MOBILSOL 44 MOBILSOL 66	MOBILSOL 44, MOBILSOL 66
PERMA CEMENT CORPORATION 5	INSTRUCTION SHEET	PERMA CEMENT
PITTSBURGH PLATE GLASS COMPANY	-	SELECTRON 5000 (SCI-101)
POLYMIR INDUSTRIES INCORPORATED	DATA SHEETS SYSTEM BROCHURE	-
REICHHOLD CHEMICALS INCORPORATED	TECHNICAL BULLETIN ON HIGHWAY AND BRIDGE RESURFACING	EPOTUF 37-128, EPOTUF 37-610, EPOTUF 37-151, EPOTUF 37-140 6
ROHM & HAAS COMPANY	DATA SHEET FOR PARAPLEX P-13 PARAPLEX P-463	PARAPLEX P-13, PARAPLEX P-463
SHELL CHEMICAL COMPANY	TECHNICAL BULLETINS	EPON 812, EPON 815, GUARDCOTE 7
SIKA CHEMICAL CORPORATION 8	INSTRUCTION SHEET	SIKA-PLUG
THIOKOL CHEMICAL CORPORATION	-	US 101 SOIL STABILIZER
UNION CARBIDE CORPORATION	DYNEL BROCHURE	-
WYANDOTTE CHEMICALS CORPORATION	BROCHURES ON URETHANE FOAMS	-

NOTES

1. AN EMULSIFIER USED FOR ASPHALTIC PREPARATION - UNABLE TO USE WITH PLASTICS. NOT TESTED.
2. PROMOTER AND CATALYST ARE USED IN COMPOUNDING POLYESTER RESINS.
3. USED AS AN EXTENDER WITH BITUMINOUS OR OTHER COATING MATERIAL. REQUIRES HEAT FOR CURING. NOT TESTED.
4. AN EMULSIFIER USED FOR BITUMINOUS PREPARATIONS OR SOIL STABILIZER. NOT TESTED.
5. PERMA CEMENT CORPORATION MATERIAL RECEIVED FROM WESTERN PERMA GLAZE CO.
6. EPOTUF 37-610 AND EPOTUF 37-140 ARE HARDENERS USED WITH EPOXIES.
7. EPON 812 AND EPON 815 SAMPLES WERE RECEIVED AS RESULT OF REQUEST UNDER THIS CONTRACT. SAMPLES OF THESE WERE ALSO ON HAND PREVIOUS TO THIS CONTRACT. GUARDCOTE IS AN EMULSIFIER USED FOR BITUMINOUS PREPARATIONS.
8. PURCHASED FROM C.R. HALL CO., SEATTLE, WN.

Fig. 3 Technical Data and Samples Received

2.3 CONCEPTS INVESTIGATION

As materials information became available, combinations of materials and application concepts were investigated. Figure 4 shows some of the various helicopter pad construction concepts that were evaluated.

MATERIALS	METHODS OF APPLICATION
NON-FOAMING LIQUID RESINS (POLYESTER, EPOXY, POLYURETHANE)	• SPRAY ON SURFACE • SPRAY REINFORCED - CHOPPED FIBERS - CONTINUOUS FIBERS - FABRICS
FOAMING LIQUID RESINS (EPOXY, POLYURETHANE)	• SPRAY POLYURETHANE OF SINGLE DENSITY ON SURFACE • SPRAY POLYURETHANE LAMINATED (2 DIFFERENT DENSITIES), HIGH DENSITY TOP AND BOTTOM, LOW DENSITY BETWEEN • SPRAY POLYURETHANE INTO HONEYCOMB STRUCTURE
FLOW-ON MATERIAL (POLYSULFIDES, GROUTS, SILICONES, ADHESIVES)	• POUR ON SURFACE

Fig. 4 Helicopter Pad Construction Concepts

2.3.1 LIQUID RESIN APPLICATION CONCEPTS

a. Manual

Figure 5 shows manual application of resin by means of a high-capacity spraying nozzle. Resin, catalyst and equipment are transported on the M35 2 1/2 ton truck. Booster pumps are powered by a separate unit mounted on the truck.

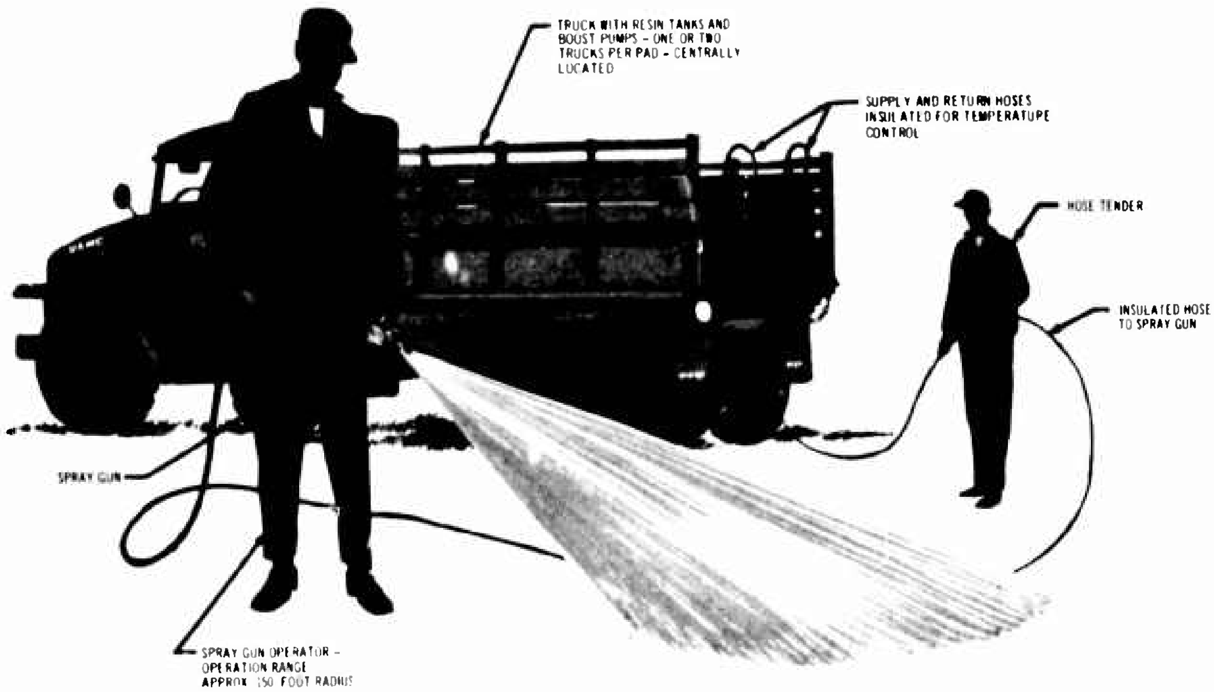


Fig. 5 Manual Application of Resin

b. Tracked Vehicle Spray

Figure 6 shows multi-nozzle application equipment mounted on a tracked vehicle. Such a system could be supplied in kit form for easy installation. Power could be drawn from the prime mover.

c. Tracked Vehicle Spray (Rolling Tank)

Figure 7 shows a partitioned rolling tank containing resin and catalyst. This tank could be pressurized and the resin discharged through a multi-nozzle spraying system.

All of these concepts could be used for foaming or non-foaming resins.

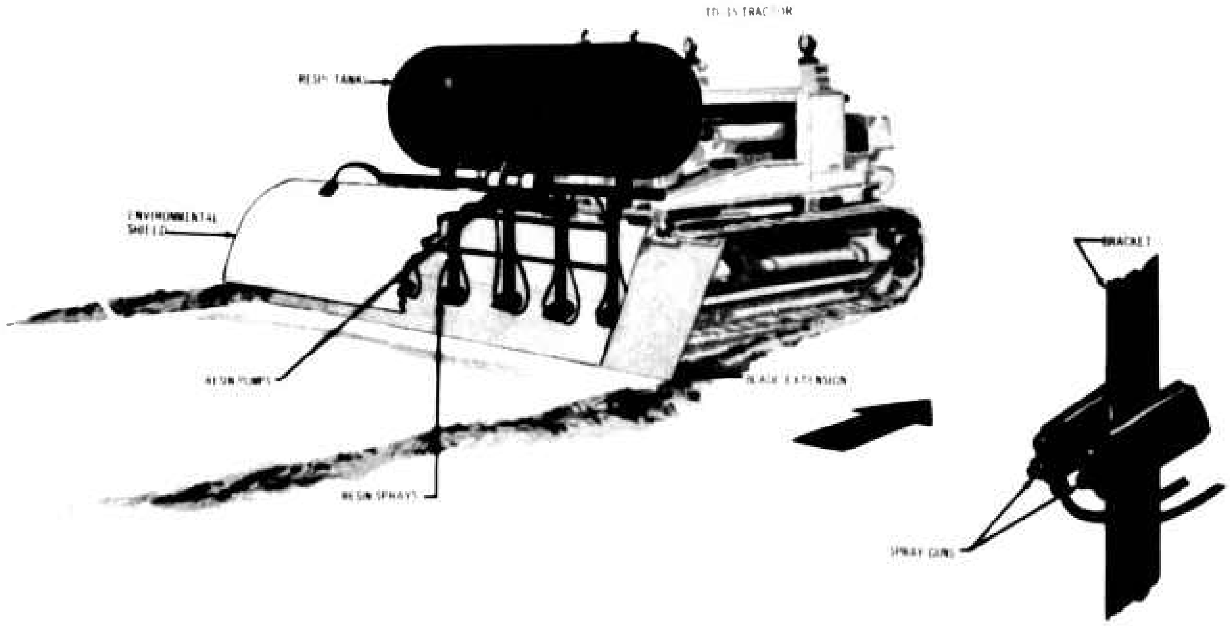


Fig. 6 Tracked Vehicle Spray

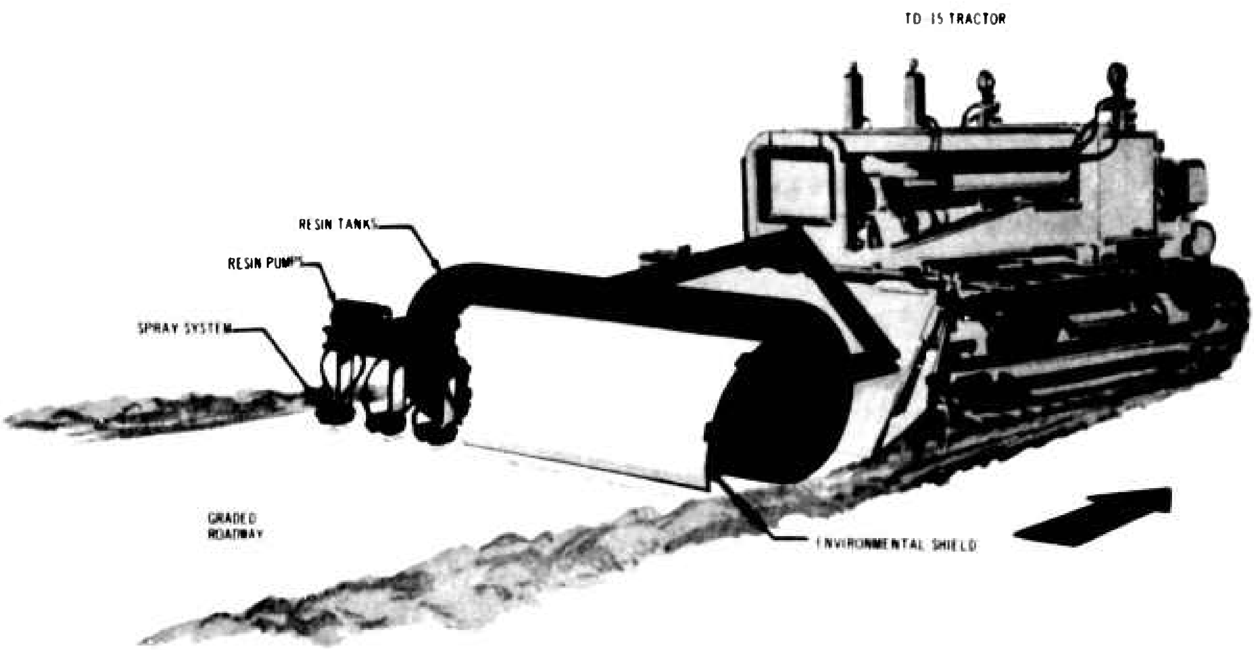


Fig. 7 Tracked Vehicle Spray (Rolling Tank)

2.3.2 REINFORCED RESIN APPLICATION CONCEPTS

a. Chopped Fiberglass

Figure 8 shows a multi-nozzle application unit with fiberglass choppers. Fiberglass reinforcement roving is supplied at each nozzle and externally mixed into the stream of resins. Such a system could be supplied in kit form for easy installation. Power could be drawn from the prime mover.

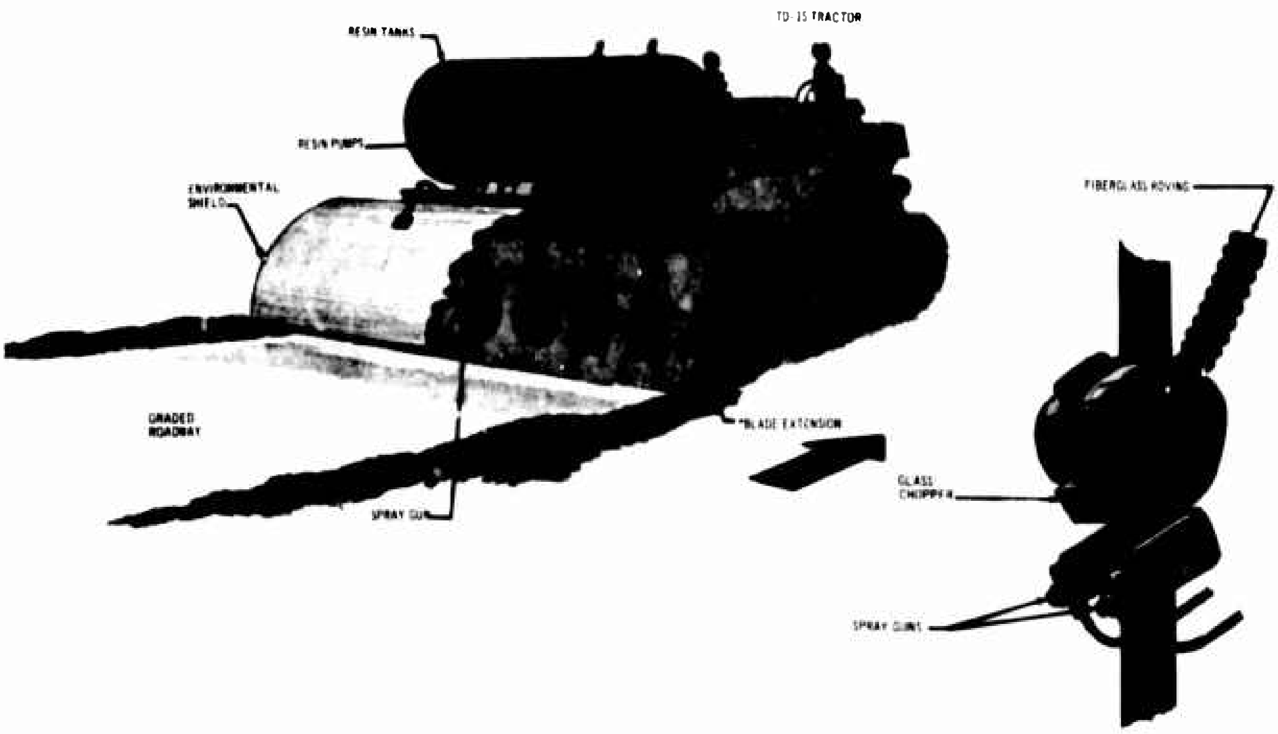


Fig. 8 Tracked Vehicle Spray of Reinforced Resin (Chopped Fiberglass)

b. Fiberglass Cloth

Figure 9 shows a multi-nozzle application unit using fiberglass fabric as reinforcement. The fiberglass fabric is supplied in a roll, deployed on the surface, and the resin is sprayed over it. Such a system could also be supplied in kit form. Power could be drawn from the prime mover.

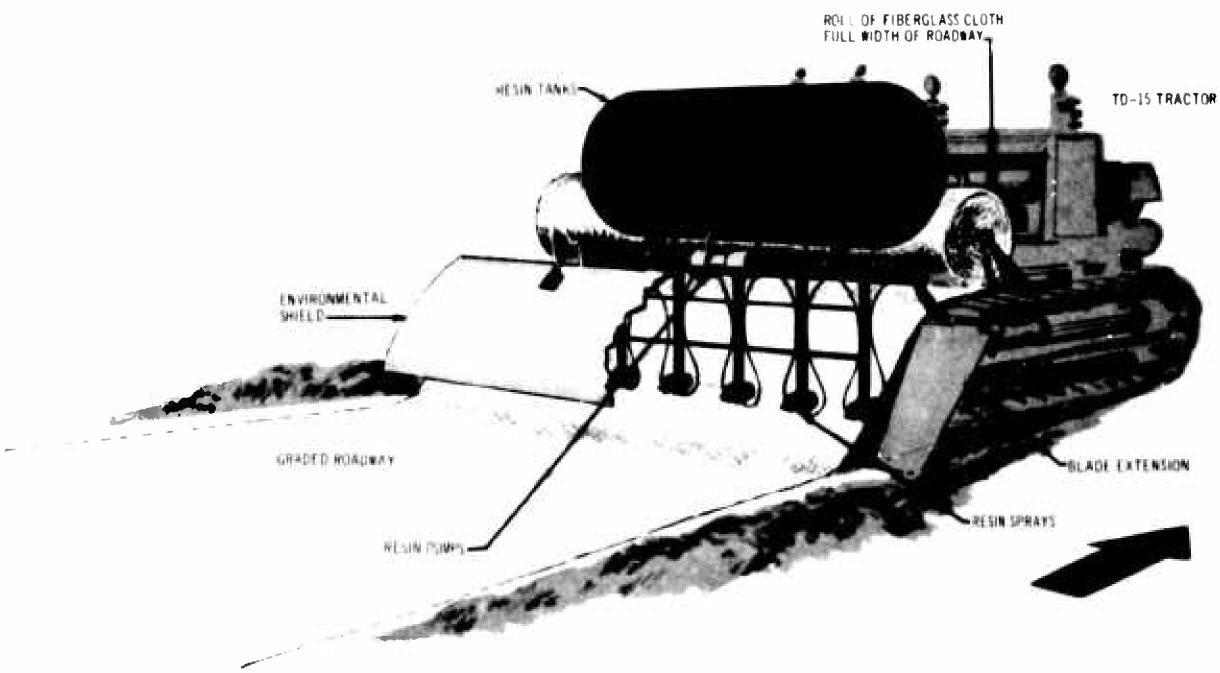


Fig. 9 Tracked Vehicle Spray of Reinforced Resin (Fiberglass Cloth)

c. Roller

Figures 10 and 11 show multi-nozzle application units towed by a prime mover. This equipment could be used for applying reinforced resin requiring rolling after application for removal of air trapped in the surfacing material.

All of the concepts showing the TD-15 tractor as prime mover are for pad preparation on low CBR soils. The M51 dump truck can substitute as prime mover for pad fabrication on high CBR soils, where no grading is required.

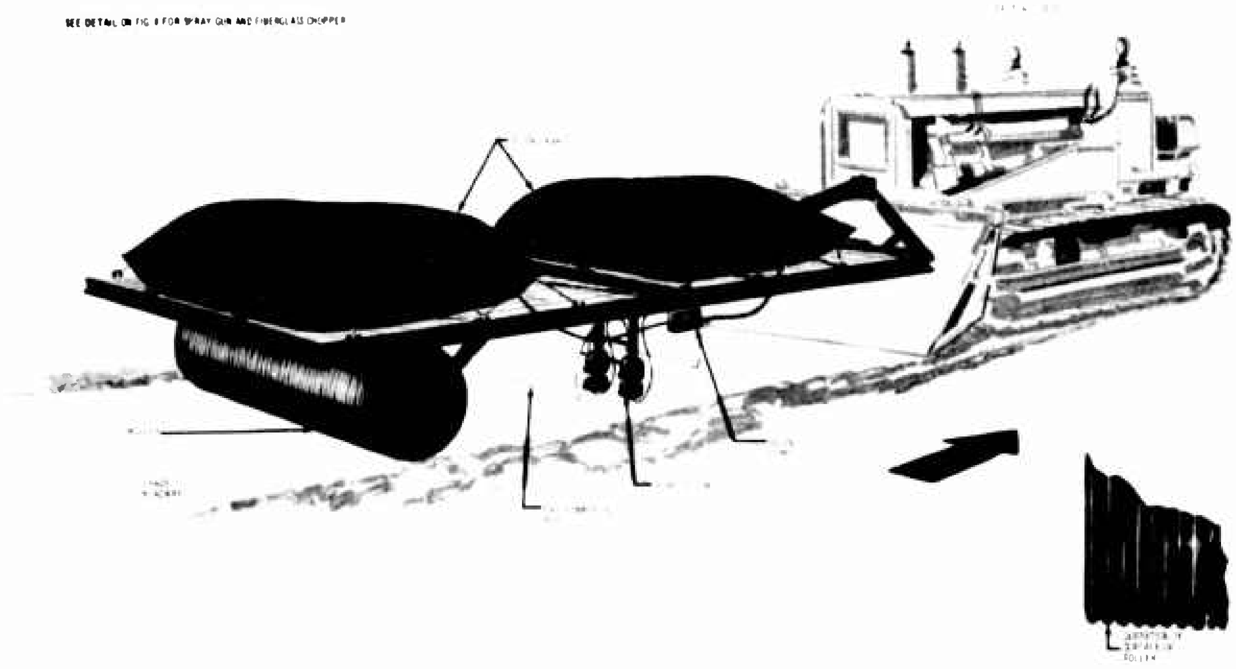


Fig. 10 Reinforced Resin Application (Separate Roller)

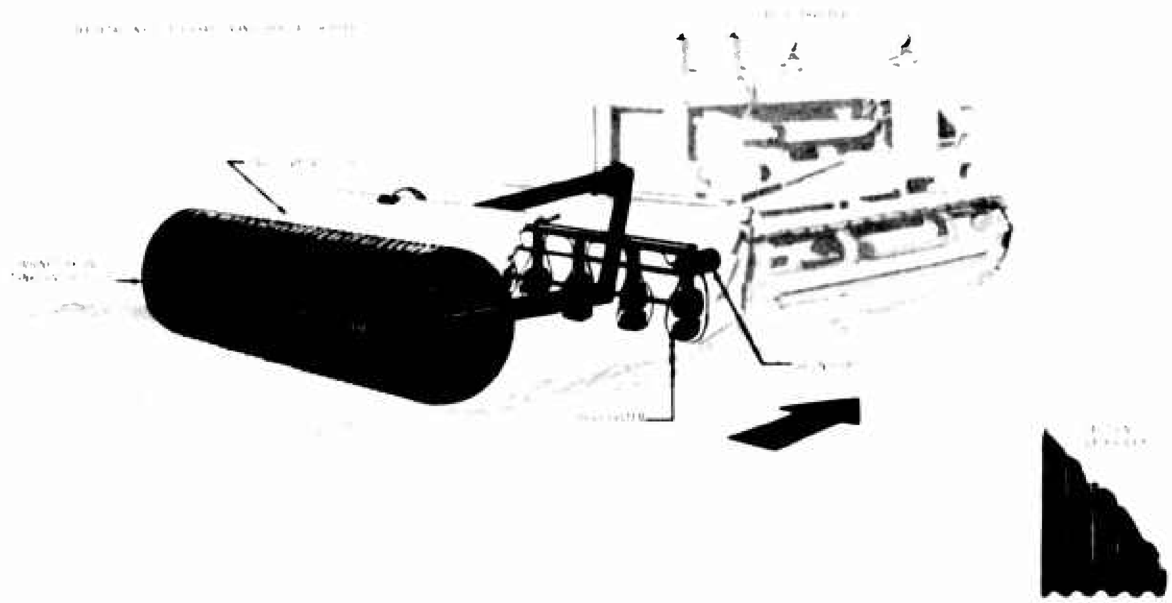


Fig. 11 Reinforced Resin Application (Rolling Tank)

2.3.3 HELICOPTER-TRANSPORTABLE APPLICATION CONCEPTS

For preparation of pads at forward or remote sites, packaged loads of premixed resin, fiberglass roving, and application equipment may be transported by helicopter. Maximum weight of the packages shall not exceed 4000 pounds gross weight for the CH-46A helicopter or 6000 pounds gross weight for the CH-37C helicopter.

a. Lightweight Manual Application System

Figure 12 shows a simple, lightweight, manual application system designed for external-sling carry by helicopter. It consists of individual 55 gallon barrels of prepared resin, fiberglass roving spool container, a skid-mounted power source and metering unit, 160 feet of hose, and a spray gun. The fiberglass storage of 35 to 70 pounds in a moisture proof container is carried on the back of the spray gun operator. The resin is transferred from the barrels through the metering device with portable pumps and hoses.

Fig. 12 Lightweight Manual Application System

b. Mobile Application System

Figure 13 shows a mobile system for applying surfacing material consisting of M 37 three-quarter ton trucks (gross weight 5950 pounds) towing M105 1 1/2 ton-trailers (gross weight 5650 pounds). The trailer tarp bows and lattice side extensions must be removed from the M105 for transportation inside the CH-37C. These trailers carry the 55 gallon barrels of premixed resin and fiberglass roving spool containers. One truck carries the power source and metering unit with application booms, transfer pumps, and hoses. Other trucks carry barrels and fiberglass as required while towing the trailers. Application booms support hoses and spray guns at their extremities. The application booms are used together on either side of the truck, not individually on each side. The resin is transferred from the barrels in the trailer to the spray guns by portable pumps. The fiberglass is supplied from a moisture-proof container on the truck through flexible tubing to the glass choppers mounted on the spray guns.

Fig. 13 Mobile Application System

2.4 LABORATORY TESTING

2.4.1 APPROACH

To efficiently evaluate the potential of each material, a laboratory testing program was conducted using curing time and strength as screening parameters. This program permitted progressive elimination of unsuitable and less promising materials so that only those with the greatest potential were subjected to further structural testing. This test program was divided into small- and large-scale testing as described in the following paragraphs.

2.4.2 SMALL-SCALE TESTING

2.4.2.1 Curing Tests

The first step in establishing material cure characteristics was to accomplish gel tests. Materials having suitable gel properties were subjected to cure tests over sand.

Gel tests were performed to verify supplier data and to determine unknown material curing characteristics. Specimens were prepared as recommended by the vendor in small containers and allowed to gel at approximately 40° F, at room temperature and at 100°C. For materials with gel time exceeding 3 hours, attempts were made to change formulation to reduce the gel time. The gel time of the materials in the polyester family was changed by varying the amount of promoter. By increasing the promoter, the gel time was reduced as shown in Fig. 14. The epoxy compounds were adjusted by varying

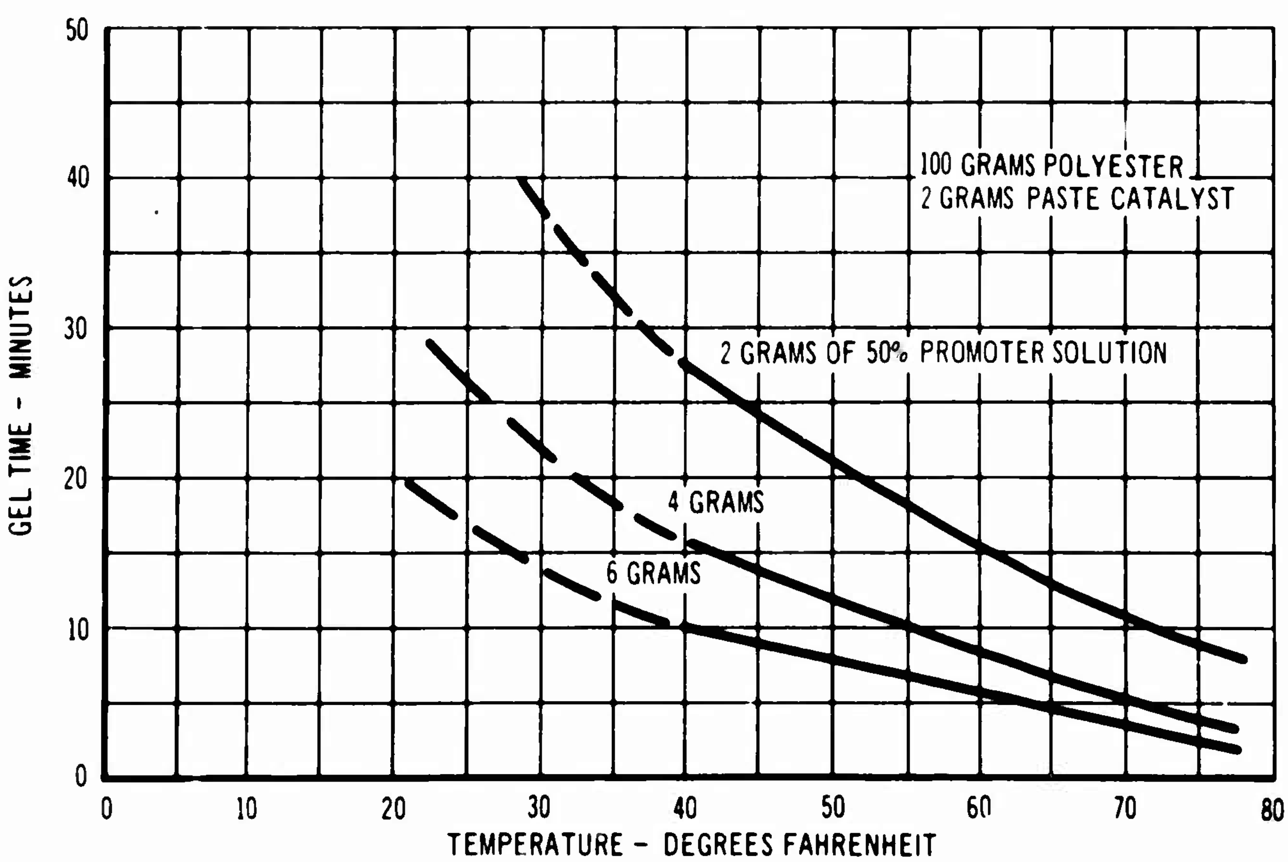


Fig. 14 Polyester Gel Time

the types of catalyst used. No change in gel time for the foam family was required. Various methods were tried to adjust the gel time of the remaining, miscellaneous materials. Emulsifiers, wetting agents, and a variety of catalysts w re introduced into the formulations not falling into the polyester, epoxy, or foam families. When formulation changes were unsuccessful, the materials were eliminated from further investigation.

Specimens of materials having the desired gel characteristics were prepared on sand. Sand having a moisture content of less than 3 percent was contained in 6 3/4 inch diameter cartons to a depth of approximately 5 inches.

The material to be tested was then poured on the sand surface as shown in Fig. 15. The amount of each material used was 100 grams, giving a surface coverage of 0.8 pound per square foot. The same amount by weight was used for each material so that a comparative strength-to-weight ratio could be obtained. In addition to cure time, material penetration into the sand was recorded. This procedure was repeated with sand containing 10 percent moisture.

Fig. 15 Material Being Poured on Sand Surface

To ensure uniformity of the above tests, a round, smooth-grained sand was chosen. This sand, known in the building trade as Plaster Sand, is composed of the following grain sizes:

100.0 %	by weight must pass through a No.	10	U.S.	standard sieve
93.5 %	by weight must pass through a No.	16	U.S.	standard sieve
60.0 %	by weight must pass through a No.	30	U.S.	standard sieve
37.2 %	by weight must pass through a No.	40	U.S.	standard sieve
15.8 %	by weight must pass through a No.	50	U.S.	standard sieve
4.9 %	by weight must pass through a No.	80	U.S.	standard sieve
1.6 %	by weight must pass through a No.	100	U.S.	standard sieve
0.04%	by weight must pass through a No.	200	U.S.	standard sieve

2.4.2.2 Structural Testing

Because of the large number of specimens that had to be tested, an expedient structural testing procedure was conceived. Specimens applied over the sand in the cartons were tested after curing, using the Tinius-Olsen Universal Tester. A piston, 3 square inches in area, was placed onto the sample as shown in Fig. 16 and a 0.1 inch-per-minute penetration rate was set on the machine. Deflection versus load was recorded automatically and loading was increased until surface breakage occurred. These data were plotted for each specimen tested. This structural testing yielded additional qualitative information such as adhesion, toughness, flexibility, and brittleness.

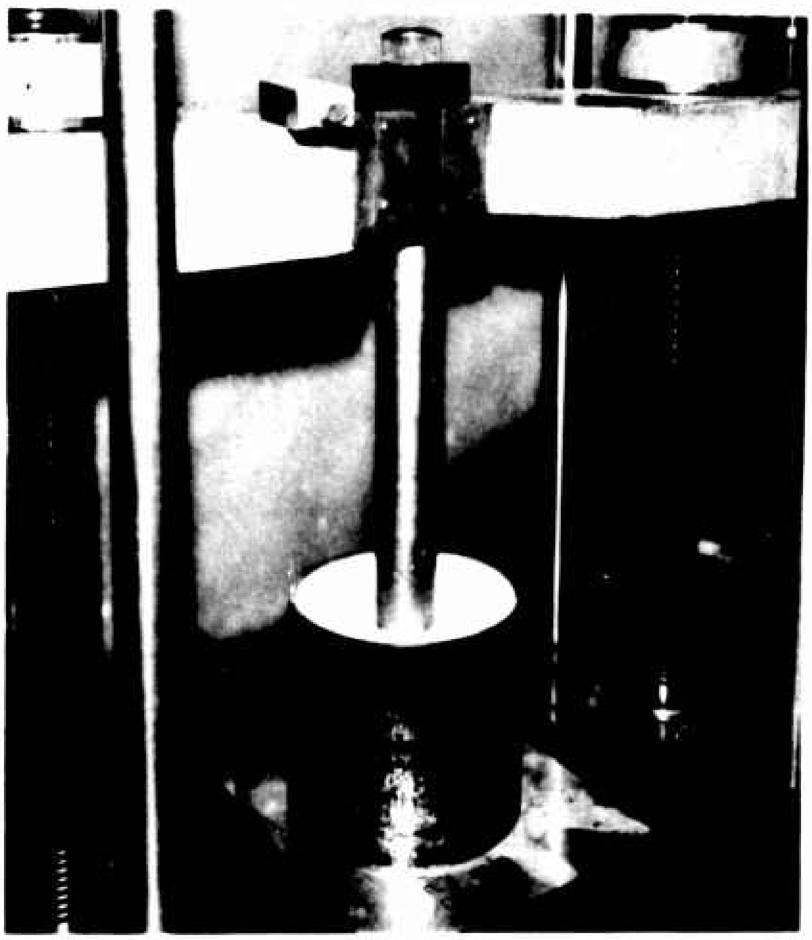


Fig. 16 Specimen Testing on Tinius-Olsen Universal Tester

2.4.3 LARGE-SCALE TESTING

Materials which exhibited the best potential from the small-scale testing were selected for large scale testing. During this testing, 3 by 5 foot specimens were sprayed over sand and a 14,000 pound static wheel load at 80 psi tire inflation pressure was applied.

Specimens were prepared for wheel load testing by spraying the material over 3 inches of plaster sand as shown in Fig. 17. The amount of material required to withstand the 14,000 pound wheel load was determined by using a diaphragm stress formula. This formula was derived from standard diaphragm equations (Ref. 4, Sect. 3). After curing, the resulting surfacing material was removed from the box and placed on a wheel load test rig.

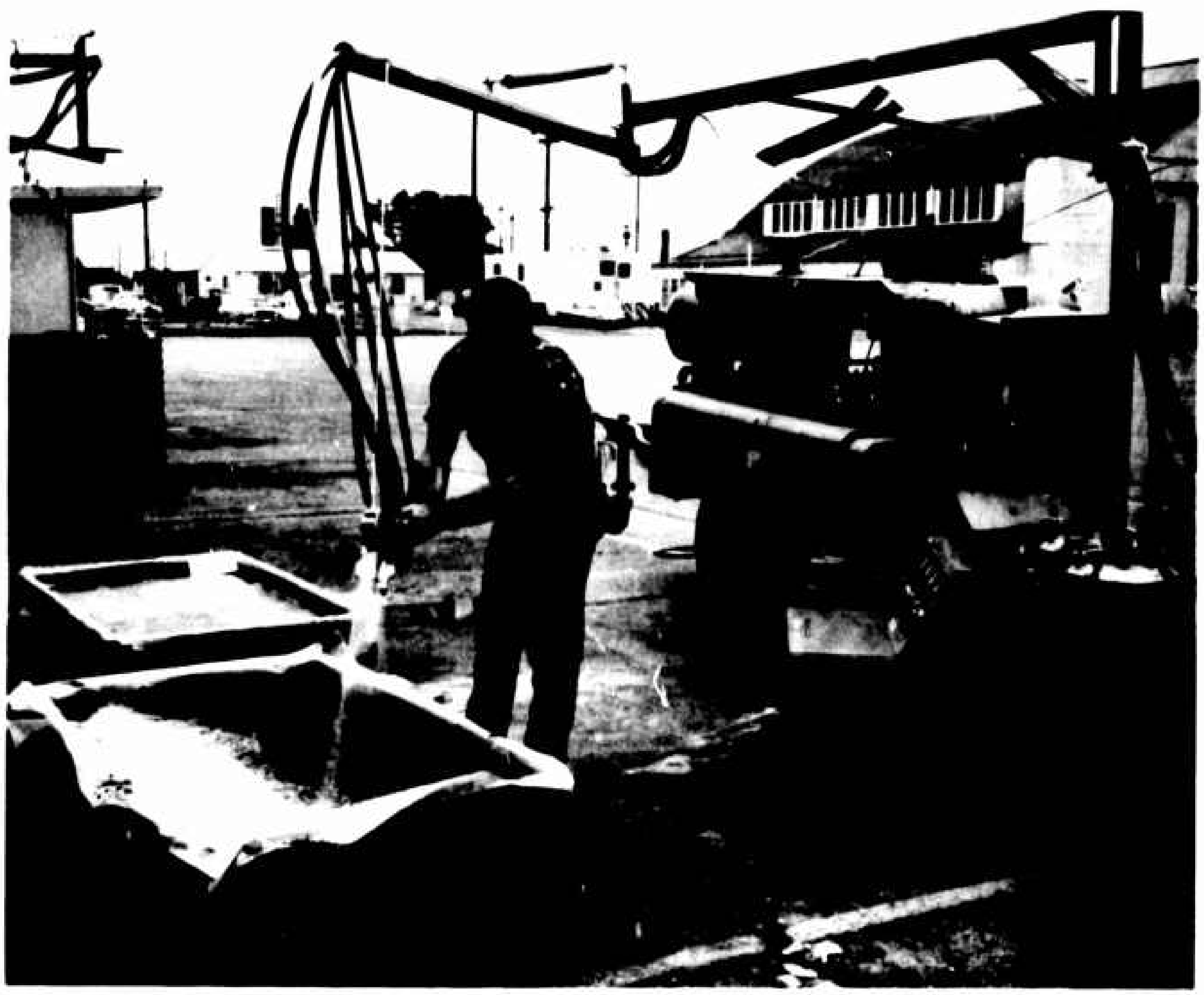


Fig. 17 Specimen Preparation for Wheel Load Testing

The Boeing wheel load test rig (Fig. 18) incorporates a sand box 7 feet by 5 feet by 27 inches. These dimensions were chosen to eliminate wall effects that would occur during testing with a smaller box. An adjustable yoke over the sand box is equipped with a hydraulic cylinder for loading a wheel with an 11 by 20, 12-ply nondirectional tread tire. The tire inflation pressure is 80 psi and maximum loading capacity of the test rig is 50,000 pounds. This test rig incorporates a truck tire and was used without modification since the tread imposes a more severe loading than a conventional helicopter tire tread of the same inflation pressure.

The specimens were placed on the sand and the wheel was lowered. Loading was increased up to 14,000 pounds and deflection was recorded. Some specimens were loaded until failure occurred. This testing, which employed a single wheel, represented a more severe loading than will be experienced during actual operating conditions since no allowance was made for tensile load distribution. Actual wheel loads will be absorbed in tension through the surfacing material as well as in compression when the material is placed on low CBR soils.

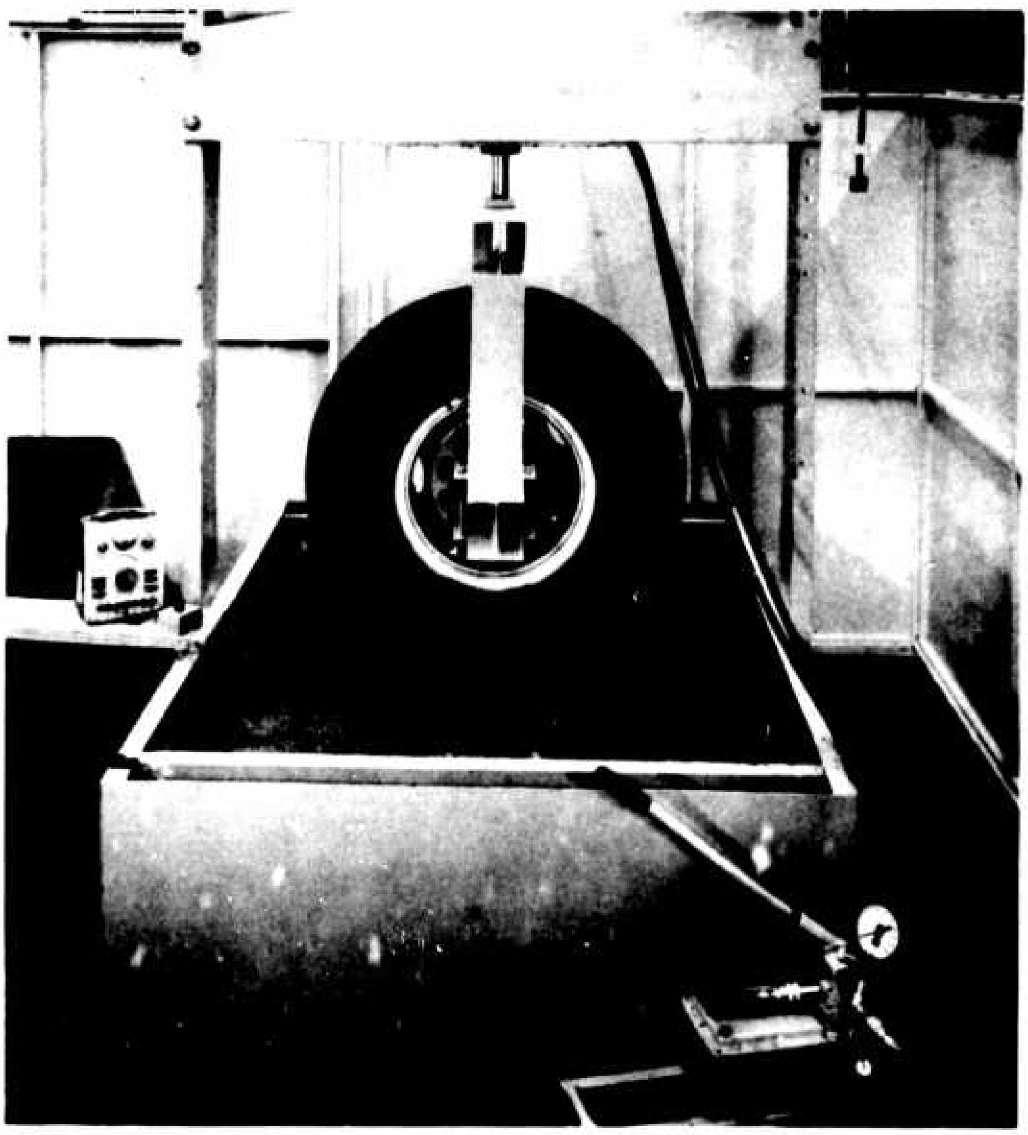


Fig. 18 Boeing Wheel Load Test Rig

2.4.4 RESULTS

2.4.4.1 Small-Scale Testing

Forty-three materials were subjected to curing tests. Sixteen materials did not cure within the 3-hour limit. One material specimen cured in too short a time to apply on the sand surface. Twenty materials were structurally tested. Three materials were not structurally tested because they were obviously too weak. The three remaining materials required penetration testing only, since strength data was available. Details of test results are shown in Appendixes A, B, and C. Figure 19 shows the curing and loading data of the five most acceptable materials. All the polyesters tested that showed fair or good strength, had viscosity below 1000 centipoise, and cost less than 25 cents per pound, were considered satisfactory materials for helicopter pad study. The epoxy selected (Specimen No. 33) from the materials investigated had the best strength, lowest cost, fastest cure time, and had satisfactory viscosity. The polyurethane selected (Specimen No. 49) had the best strength, cure time, and cost of all those acceptable. Figure 20 shows a sample of polyester resin after small-scale structural testing and Figure 21 shows a polyurethane foam sample after small-scale testing.

MATERIAL CATEGORY	SPECIMEN NO.	CURING TIME AT ROOM TEMP.		STRUCTURAL TESTING MAX. LOAD.	
		DRY SAND	WET SAND	LOAD LBS	PSI
POLYESTER	2	15 MIN	30 MIN	2640	880
POLYESTER	5	15 MIN	20 MIN	2670	890
POLYESTER	11	10 MIN	20 MIN	5850	1950
EPOXY	33	60 MIN	120 MIN	5760	1920
FOAM	49	3 MIN	3 MIN	3930	1310

Fig. 19 Curing and Loading Data

2.4.4.2 Large-Scale Testing

Based on the results obtained during small-scale testing, large specimens of polyester, epoxy, and foam were prepared. Curing cracks developed in the unreinforced polyester and epoxy samples that were formulated for a rapid cure of 30 minutes. The maximum wheel loads obtained on these rapidly cured samples were 2000 pounds. By changing the catalyzations to prolong the cure time to 1 hour, no visible curing cracks developed. These longer cured samples withstood 4000 pounds. Although further extensions of cure time would increase material strength, no unreinforced material was found which could practically meet the 14,000 pound wheel load. In addition, a polyester sample sprayed on hot sand (100°F) cured on the surface with little penetration. To solve these problems, chopped fiberglass was added to the polyester and epoxy resins. No curing cracks were experienced in specimens

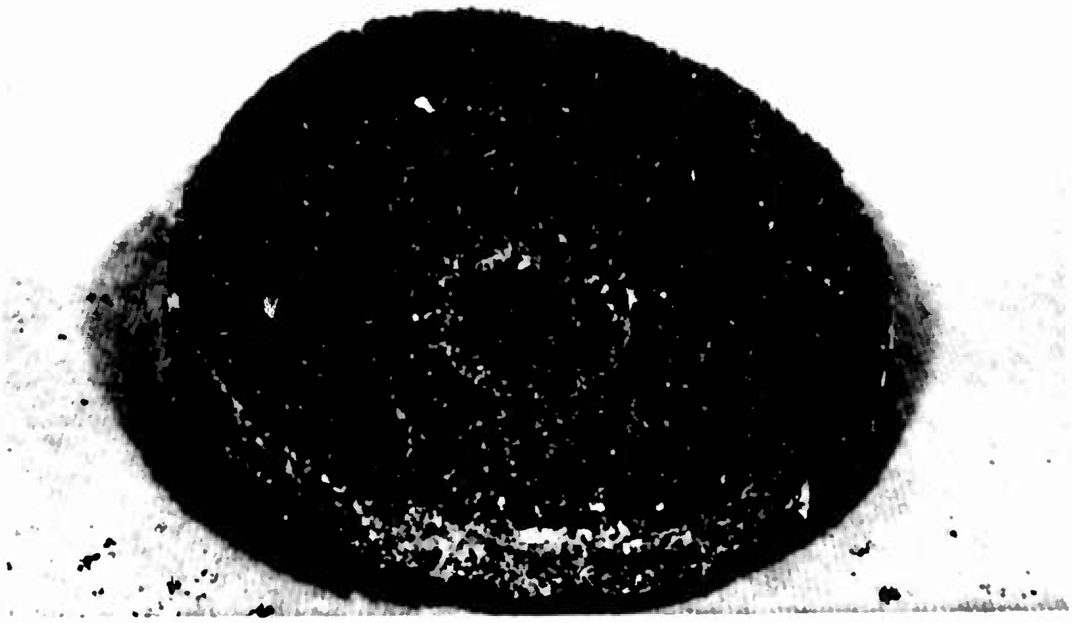


Fig. 20 Polyester Sample After Small-Scale Structural Testing

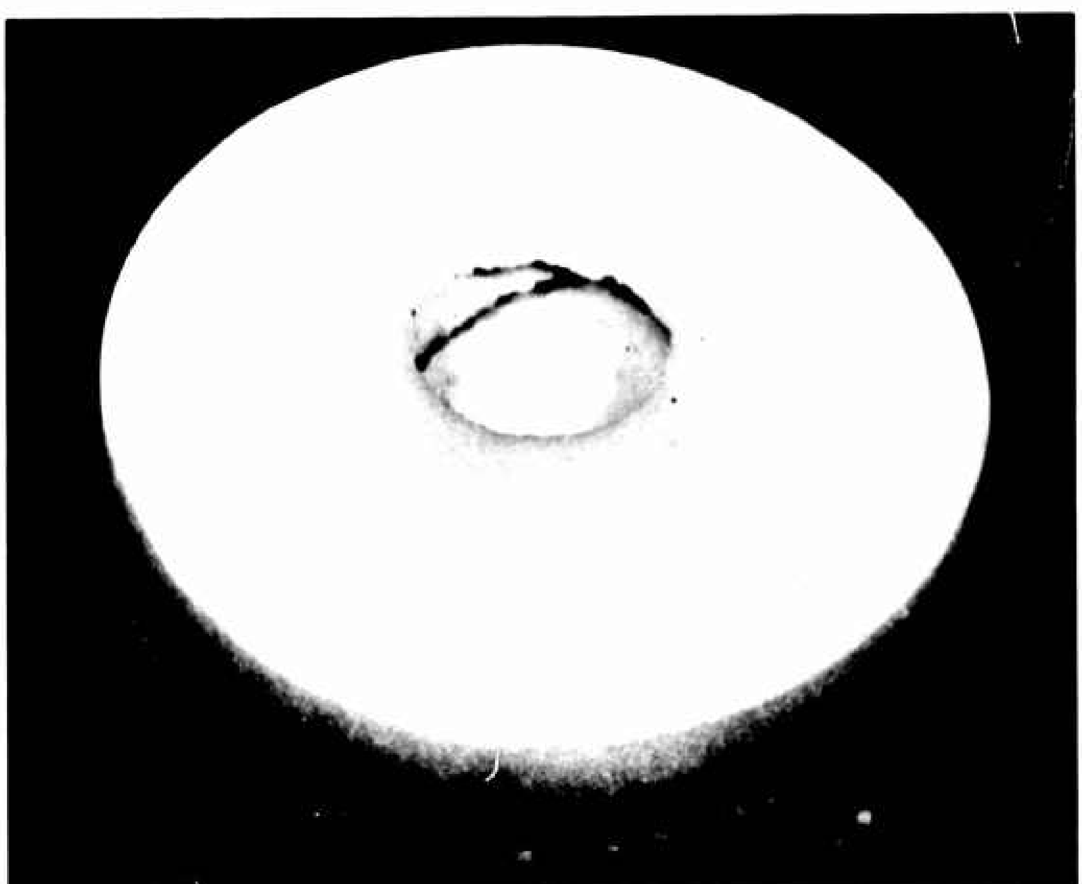


Fig. 21 Polyurethane Foam Sample After Small-Scale Structural Testing

prepared with fiberglass reinforcement. The following specimens were prepared and subjected to a 14,000 pound wheel load:

a. Reinforced Polyester Material Specimen No. 11

This specimen (Fig. 22) was sprayed with 17 percent chopped fiberglass. The average thickness was 0.20 inch, corresponding to approximately 2 pounds per square foot of surfacing material. The specimen withstood a 10,000 pound wheel load with a deflection of 2 3/4 inches as shown in Fig. 23. The specimen withstood the 14,000 pound wheel load with a deflection of 3 inches.

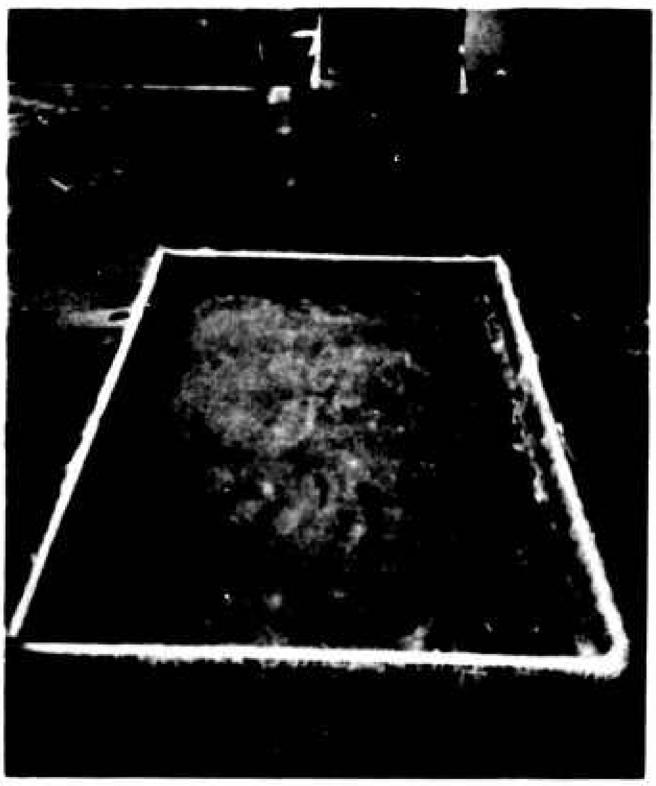


Fig. 22 Reinforced Polyester Material (Specimen No. 11)

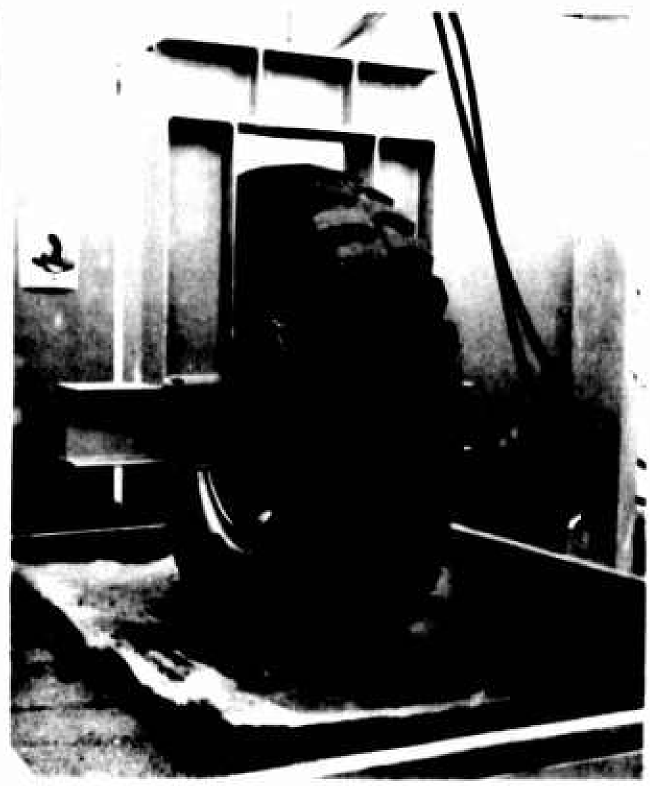


Fig. 23 Specimen No. 11 Under 10,000 pound Wheel Load

b. Reinforced Polyester Material Specimen No. 2

This specimen was sprayed with 35 percent chopped fiberglass. The average thickness was 0.20 inch, corresponding to approximately 2 pounds per square foot of surfacing material. This specimen also withstood the 14,000 pound wheel load with a deflection of 3 inches.

c. Reinforced Polyester Material Specimen No. 5

This specimen was sprayed with 12 percent chopped fiberglass. The average thickness was 0.12 inch, which corresponded to approximately 1.2 pounds per square foot of surfacing material. Reinforcement separation occurred at 3,000 pounds with failure at 9,000 pounds, at a deflection of 4 1/4 inches.

d. Reinforced Epoxy Material Specimen No. 33

This specimen (Fig. 24) was sprayed with 32 percent chopped fiberglass. The average thickness was 0.20 inch, corresponding to approximately 2 pounds per square foot of surfacing material. This specimen withstood the 14,000 pound wheel load with a 3 inch deflection. Figure 25 shows the specimen under 10,000 pound wheel load with a deflection of 2 1/4 inches. A similar specimen was sprayed with 19 percent chopped fiberglass. The average thickness was 0.125 inch, corresponding to approximately 1.2 pounds per square foot. This specimen withstood a 10,000 pound wheel load with a 4 1/2 inch deflection.

e. Polyurethane Foam Material Specimen No. 49

This specimen was poured to an average thickness of 1.0 inch. Failure occurred at a 3700 pound wheel load with negligible deflection as shown in Fig. 26.

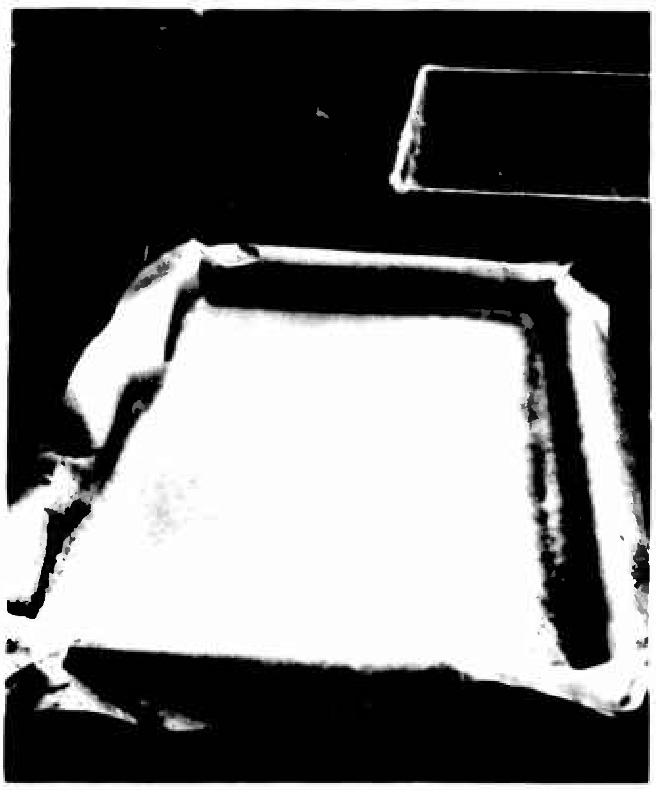


Fig. 24 Reinforced Epoxy Material (Specimen No. 33)

Fig. 25 Specimen No. 33 Under 10,000 Pound Wheel Load

Fig. 26 Polyurethane Foam Material (Specimen No. 41) Showing Failure Under 3700 Pound Load

2.4.4.3 Plastic Surface Reinforcement Ratios

As a general rule, commercial manufacturers of reinforced plastics apply materials at a ratio of 35 percent fiberglass-to-resin by weight. Materials using this ratio require rolling following application to remove entrapped air and to obtain maximum strength. To eliminate this rolling requirement and obtain optimum strength, a ratio of 20 to 25 percent was chosen for large-scale testing. However, the resulting ratios varied due to variation in application techniques and absorption of the resin by the sand. As shown in Fig. 27, fiberglass percentages as low as 12 percent had minimum effect on the resulting surface material strength.

2.5 APPLICATION EQUIPMENT REVIEW

A preliminary investigation into future military field application equipment was accomplished through a review of commercially available equipment.

2.5.1 TWO-COMPONENT SYSTEMS

Two-component systems discussed herein are those using mixtures that are divided into liquids prior to mixing for final compounding and curing.

RESIN	MATERIAL SPECIMEN NUMBER	SURFACE THICKNESS (INCHES)	RESIN & GLASS COVERAGE (LB/FT2)	FIBER-GLASS (% BY WT)	LOAD (LBS)	DEFL. (INCHES)
POLY-ESTER	11	0.20	2.0	17	10,000	2 3/4
POLY-ESTER	11	0.20	2.0	17	14,000	3
POLY-ESTER	2	0.20	2.0	35	10,000	2 3/4
POLY-ESTER	5	0.12	1.2	12	9,000	4 1/4
EPOXY	33	0.20	2.0	32	10,000	2 1/4
EPOXY	33	0.12	1.2	19	10,000	4 1/2
POLY-URETHANE FOAM	49	1.00	1.5	0	3,700	0

Fig. 27 Reinforced Plastic Surface Characteristics

2.5.1.1 Internal Mixing

Internal mixing is most commonly used for two-component systems. Figure 28 illustrates a typical system.

For sprayable polyester compounds, a simple mixing procedure is used since intimate mixing is not required to provide a satisfactory compound. The two resin components are brought together in the head of the spray gun and combined while passing through a mixing plate. After they are combined, the mixture is then picked up in an air stream, which governs the spray pattern and particle size. A solvent must be readily available to flush the gun and/or hoses when spraying is stopped.

For sprayable epoxy or polyurethane foam compounds, intimate and exact mixing is required. As the two components are brought together in the spray gun, they are mixed within a chamber containing baffles and a high-speed revolving agitator. This agitator may be driven either by hydraulic, pneumatic, or electric motor. After the compound leaves the mixing chamber, it is then picked up in an air stream, which governs its spray pattern and particle size. A solvent system must be connected to each component port in the spray gun for adequate flushing at the end of each spray operation.

The two components required for the system must be pumped to the spray gun from the supply source. Either of two pumping methods may be

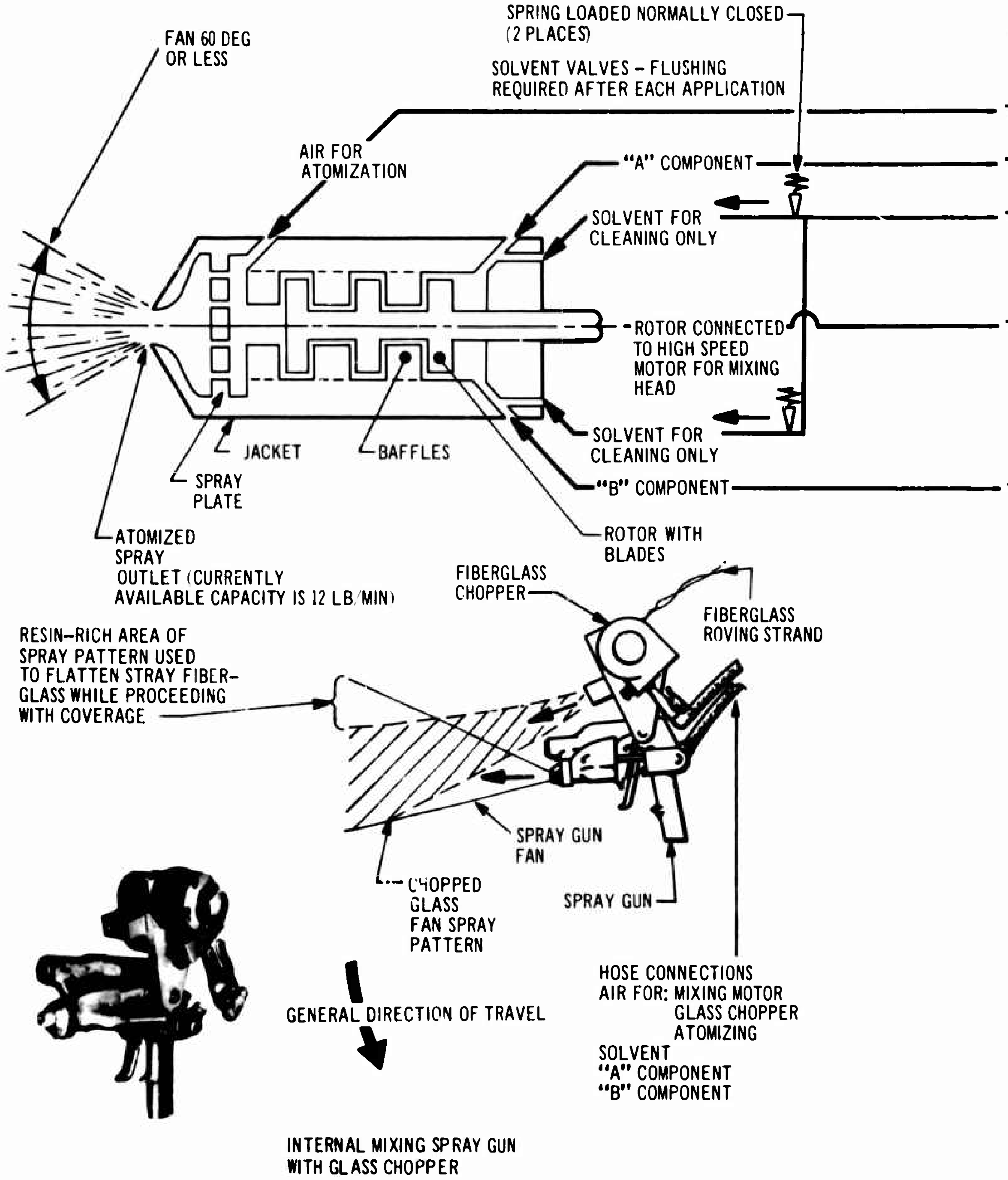
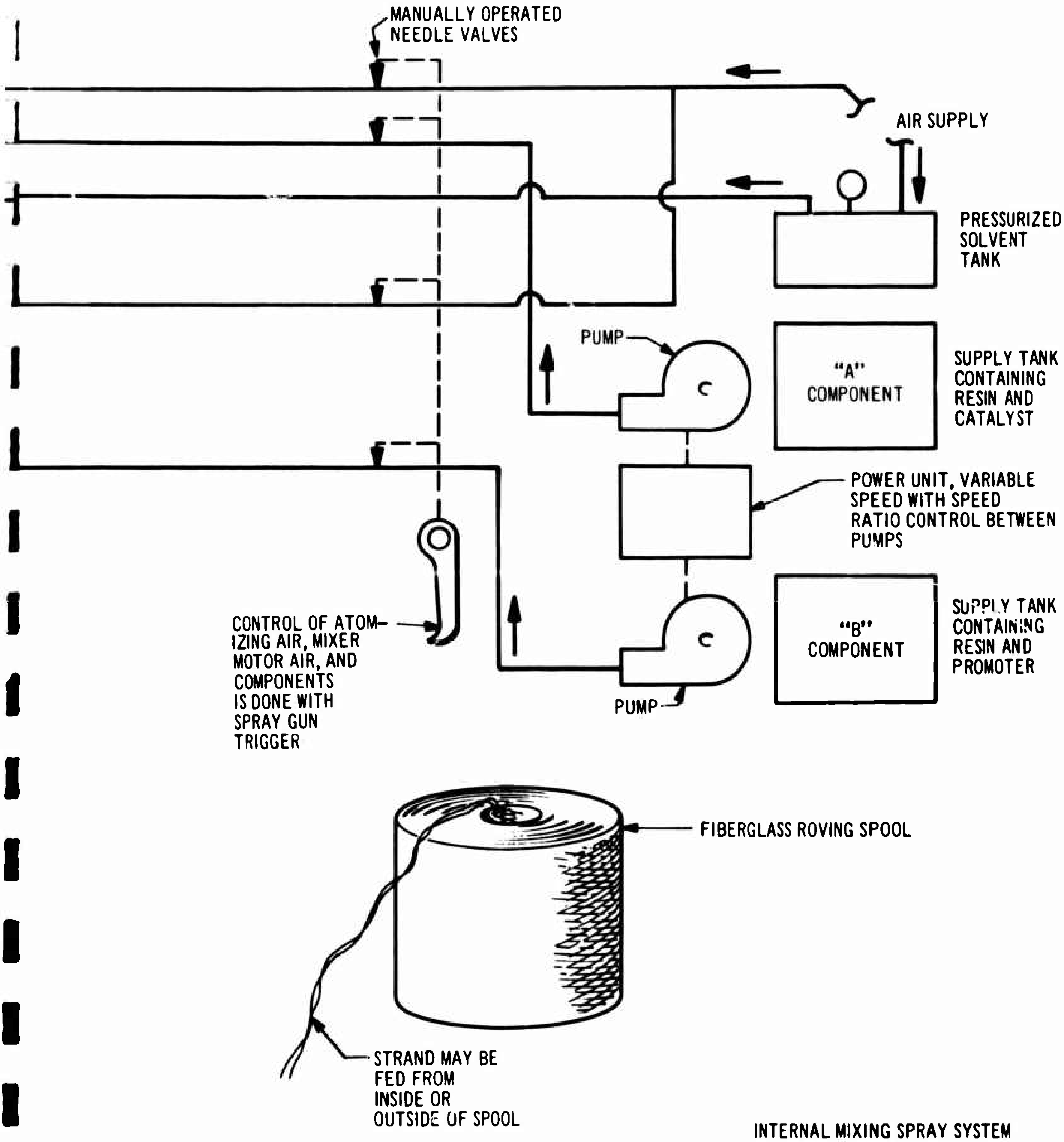


Fig. 28 Internal Mixing System and Gun Photo



INTERNAL MIXING SPRAY SYSTEM

used: reciprocating pumps, which are mostly air actuated; or rotary pumps, most of which are off-set impeller type, driven by hydraulic, pneumatic or electric motors. A popular method of metering polyester components for internally mixed compounds is to transfer the catalyzed resin with a large pump and to meter a small percentage of promoter from a pressurized vessel through a flow meter.

Chopped fiberglass may be added to either the sprayed polyester or the epoxy, resulting in a reinforced plastic. Chopped fiberglass is added to the polyester resin stream a few inches downstream of the nozzle. Fiberglass is furnished in a form known as roving, which varies in weight, as required, by changing the number of strands per roving thread. The amount of glass used may be varied during spraying by adjusting the speed of the glass chopper. This roving is fed through a rotary knife chopper which is driven by an air motor, where it is chopped into the desired length, usually from 3/4 inch to 2 inches long, and blown into the resin stream. About 3 air horsepower at 100 psi is required for this process per glass chopper.

A specialized unit for dispensing foam polyurethane is commercially available on a lease basis. Nitrogen gas is utilized as the pumping agent. It is used to pressurize the component tanks and operate a frothing head agitator.

2.5.1.2 External Mixing

At the present time, external mixing two-component systems can only be used for spraying polyester compounds composed of a promoted resin component and a catalyzed resin component. The promoter and the catalyst should be added to the resin not more than a few hours prior to use to avoid premature gelling. Figure 29 illustrates a typical external spray system.

The same pumping methods may be used for external mixing systems that are used for internal mixing systems. The two components are delivered to the spray gun where they are fed through separate nozzles. The flow is controlled simultaneously from a single actuator (trigger). The two, narrow, fan-type sprays mix approximately 15 to 18 inches from the nozzles. Chopped fiberglass may be added to this stream of polyester as previously described. Due to a larger resin particle size and greater particle momentum, a higher impingement of the compound is experienced on the applied surface than is possible with internally mixed air-sprayed resin and fiberglass. No rolling of the surfacing is required to remove entrapped air when an external-mixing system is utilized. Larger particles also resist being blown from their intended path. The external-mixing system should be flushed with solvent following use, but this flushing is less critical than for an internal-mixing system.

2.5.2 ONE-COMPONENT SYSTEM

A one-component (premixed compounds) system utilizes fluid which is mixed prior to spraying. The pumping is done either by reciprocating or rotary pumps. The spray gun is similar to a paint gun. The fluid may be atomized either by an air stream or by particle breakdown due to high pressure release through a small orifice in the nozzle spray plate. Chopped fiberglass may be used with this system as previously described.

2.5.3 VEHICLES

Two probable areas have been considered for helicopter pads: a) a semi-permanent location utilizing heavy equipment not transportable by helicopter, and b) remote- or forward-site utilizing equipment supplied from a helicopter.

2.5.3.1 Non-Helicopter Transportable Vehicles

The following factors affect the choice of a vehicle for use at semi-permanent locations:

a. Bearing load of the vehicle must be light enough to allow travel over soil having extremely low bearing capacity.

b. The vehicle must have a weight-carrying capacity adequate to transport the equipment and material required to prepare a helicopter pad 150 feet by 150 feet. The material and equipment weight is estimated to be 10,000 pounds for the preparation of a helicopter pad on uncompacted (cone index 30 at 6-inch depth; CBR less than one) sand. The weight of material decreases appreciably for higher CBR soils.

c. The vehicle must be capable of constant slow-speed travel over various grades and different types of ground.

d. It would be desirable to furnish additional equipment for attachment to available military inventory equipment to meet the above requirements.

2.5.3.2 Helicopter Transportable

The following factors affect the choice of equipment for use at remote or forward sites:

a. Gross weight of individual packages must not exceed 6000 pounds to allow for helicopter transport.

b. Vehicle ground floatation should allow travel over soil having extremely low bearing capacity.

c. The vehicle must have a weight-carrying capacity adequate to transport the equipment and material required to prepare a 150 by 150 foot helicopter pad.

d. The vehicle must be capable of constant slow-speed travel over various grades and different types of ground.

e. It would be desirable to furnish additional equipment for attachment to available military inventory equipment to meet the above requirements.

2.5.4 FINDINGS

The external-mixing system for dispensing polyesters is the most dependable reusable system because of its lesser dependence upon prompt, thorough flushing with solvent. The external-mixing system spray gun nozzles are also simpler than the internal-mixing system guns. In addition, the larger particle size of externally mixed compounds are less prone to dispersal by wind

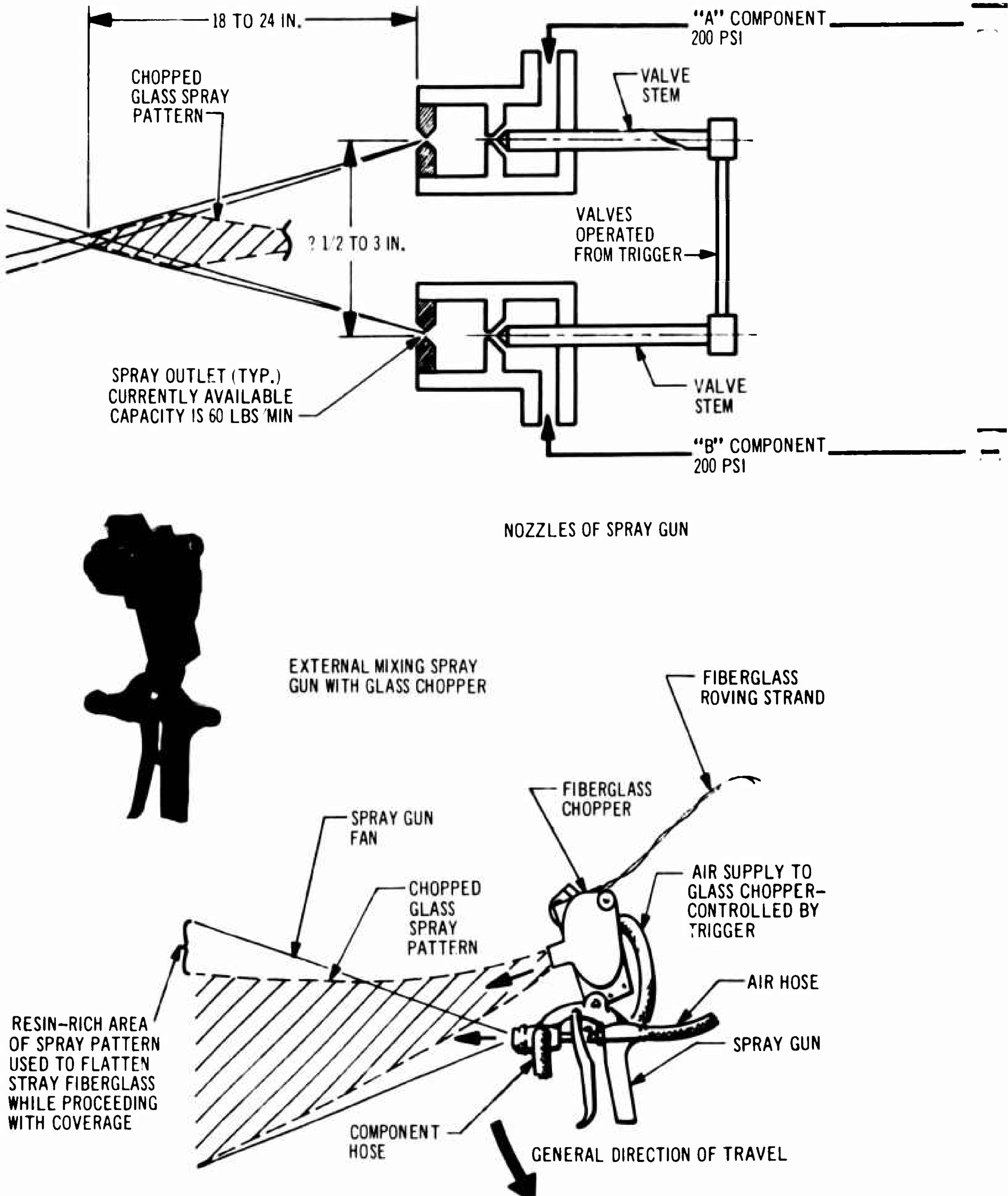
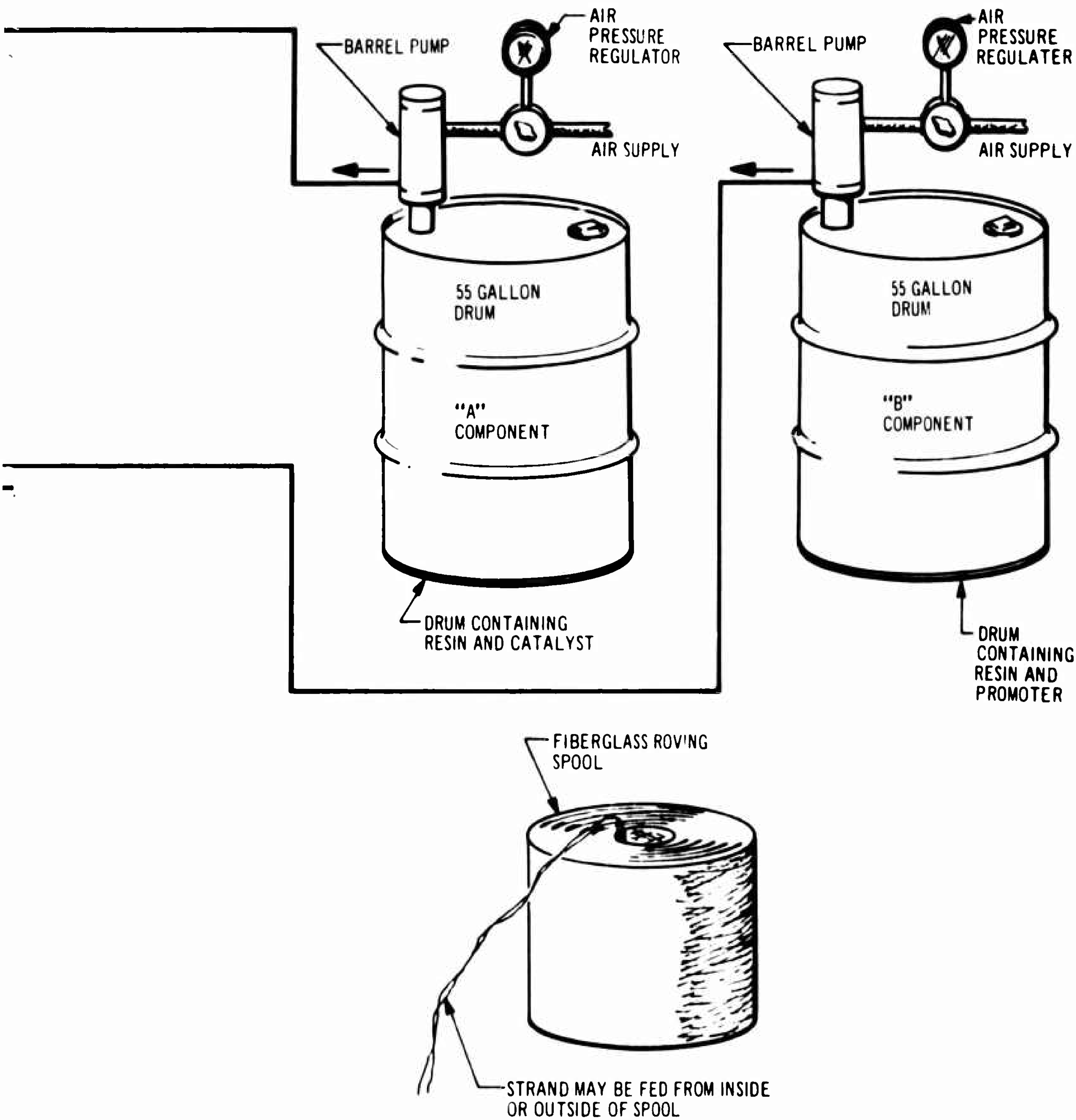


Fig. 29 External Mixing System and Gun



EXTERNAL MIXING SPRAY SYSTEM

than are air atomized particles; therefore, less material is lost when using the external-mixing system. Single-component systems are simpler, but are restricted in operation by the gel time of the material being sprayed. The equipment must be cleaned before the compound gels or it must be discarded.

For helicopter pad preparation at semi-permanent locations, the TD-15 tractor was selected from current Marine Corps vehicles as being the most suitable on low CBR soils. The M51 dump truck was considered to be a good alternate vehicle for pad fabrication on high CBR soils. The application equipment kit considered for use with the TD-15 tractor could also be used with this truck with minor modifications. For situations where downwash is the only problem and pads are required on high CBR soils, the use of a M35 two and one-half ton truck is considered adequate. This truck has the load-carrying capability for the transportation of the necessary materials and manually operated application equipment as shown in Fig. 5.

For helicopter pad preparation at remote or forward sites, the equipment must be unitized for lift by helcopters. Where ground mobility of application equipment and material is a requirement, following aerial delivery to a central point, M37 trucks and M105 trailers are satisfactory. However, providing this mobility increases airlift cost per pad. Consideration should be given to the concept shown in Fig. 12.

2.6 CONCLUSIONS AND RECOMMENDATIONS

It is concluded that on-site fabrication of helicopter pads using lightweight, rapid curing materials is feasible. Reinforced polyester, reinforced epoxy, and polyurethane foams have shown the best potential for the preparation of helicopter pads. Other materials have been ruled out for the present as not offering a current practical solution to the problem. These materials involve either prohibitive costs, extreme thickness of application, or complex application equipment. Based on today's resin characteristics and application equipment technology, it appears that an on-site fabricated helicopter pad concept using sprayed reinforced polyester presents distinct advantages over other concepts. In addition, a system using reinforced polyester could be developed rapidly and made operational with a minimum of development risks. Proven spraying equipment is used extensively throughout industry and could be modified for field application in a short time.

2.6.1 REINFORCED POLYESTER

Reinforced polyester with 17 to 35 percent fiberglass sprayed on top of sand will withstand the required 14,000 pound wheel load when applied at an average thickness of 0.20 inch. The weight of material required for such a surfacing is approximately 2 pounds per square foot. At present commercial rates, the cost of material for such a surfacing is approximately 60 cents per square foot. However these costs can be lowered since the amount of material required can be reduced for soils of higher CBR's than sand. Recent tests (Ref. 5, Sect. 3) indicate that one-half pound per square foot of polyester withstands sustained downwash dynamic pressures over 145 pounds per square foot which greatly exceed the maximum downwash pressure of 7 pounds per square foot of the Marine Corps helicopters. Therefore, it is concluded that wheel loading only dictates the material thickness requirements.

2.6.1.1 Polyester Resin Characteristics

Most of the polyester resins tested exhibited the required curing and strength characteristics and presented advantages such as ability to be compounded for rapid curing under adverse temperature and moisture conditions. Contrary to other resin systems, the catalyst-resin ratio is not as critical for polyesters, an important feature when rapid curing is desired without extensive strength losses.

Costs of the various resins vary according to the basic compounding requirements. Certain characteristics such as fire resistance, thixotropy (change in viscosity with particle motion), and coloring have been introduced into the basic compounds affecting their costs. Such characteristics may not be required for the helicopter pad application. Resin specifications should be defined to obtain a compound meeting the helicopter pad requirements at the lowest cost.

2.6.1.2 Application Equipment

Polyester resins can be sprayed either with internal-mixing or external-mixing application equipment. The external-mixing, low pressure spraying system described in Par. 2.5.1.2 sprays large particles, which eliminates requirements for rolling to remove trapped air and results in simplified application equipment design. At the present time, commercially available units have dispensing capabilities up to 60 pounds per minute per nozzle. A concept using units such as the multi-nozzle spraying systems described in Par. 2.3.2 could prepare a 150 by 150 foot helicopter pad in approximately one hour.

2.6.2 REINFORCED EPOXY

When cured in contact with moisture, only one epoxy compound cured within the 3-hour limit. This epoxy resin, sprayed with 32 percent fiberglass and applied at an average thickness of 0.20 inch, withstood the 14,000 pound wheel load. The weight of the material was 2 pounds per square foot. A test sample having a thickness of 0.125 inch, withstood 10,000 pounds; however, a large deflection was observed.

As a general rule, epoxies have higher costs and higher toxicity than polyesters. In addition, the criticality of the catalyst-resin ratio and the need for intimate mixing require internal-mixing application equipment. Epoxies have higher strength-to-weight ratio than polyester resins, and it is possible that future epoxy compounds will compare favorably with the polyesters for helicopter pad applications.

2.6.3 POLYURETHANE FOAM

Polyurethane foams possess characteristics which make them attractive for future development work. They cure within 2 minutes to 70 percent of their maximum strength and are not affected by moisture. At the present time, complex application equipment is required for spraying high-density foam and strict temperature control is required to maintain desired foam density. However, if simplified foam application systems are developed in the future, this material should be reconsidered for surfacing applications.

2.6.4 MISCELLANEOUS

None of the miscellaneous compounds tested compared favorably with the strength and curing characteristics of the reinforced polyester for rapid surfacing systems.

2.6.5 FOLLOW-ON ACTIVITY

In view of the results obtained in this study, the following activity is recommended:

a. Full-scale helicopter pads should be prepared for testing using modified commercial application equipment. Such a test program would use current material technology and the present state of the art in application equipment. The helicopter pad should be prepared on a low CBR soil and subjected to helicopter operations for an extended period of time. These tests should verify the laboratory test results, evaluate pad resistance to aircraft operation, and determine the weatherability and repairability of the pad. Such a test program would efficiently demonstrate the operational potential of the on-site fabrication concept and provide the necessary information for early development of operational equipment.

b. Procurement specifications should be prepared which define the polyester characteristics required to meet military needs. Emphasis should be on shelf life, curing requirements, strength, and cost.

c. Continue to survey and evaluate polyester, epoxy, and foam formulations so that on-site fabrication of helicopter pads will benefit from the manufacturers' latest research. Since plastic and chemical technology is moving at a fast pace, the search should be continued for satisfactory single-component materials that may result from future research.

d. Design and test field application equipment capable of preparing a helicopter pad at semi-permanent locations with reinforced polyester at a vehicle speed of approximately 30 feet per minute in 12-foot-wide increments. Such equipment should be capable of preparing a 150 by 150 foot helicopter pad in approximately an hour.

e. Design and test helicopter-transportable application equipment for use at remote or forward sites. The equipment should be packaged to permit external-sling transportation by helicopter and should be configured to be compatible with ground vehicles available at remote or forward sites. The combined weight of the unitized application equipment and ground vehicles should also allow for transportation by helicopter.

f. The equipment described in d and e above should be designed and built so that it can be operated by semi-skilled military personnel under combat conditions. Basing the design on the reinforced polyester concept and on the experience gained in the recommended full-scale test program will result in the earliest practical operational system.

3.0 REFERENCES

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APPENDIX A

MATERIALS CHARACTERISTICS

The general characteristics of all materials that were evaluated during the small-scale test program are shown in the following figures. The materials are grouped into the following general categories:

a. Polyesters (Fig. A-1)

b. Epoxies (Fig. A-2)

c. Foams (Fig. A-3)

d. Miscellaneous (Fig. A-4)

SPECIMEN NUMBER (NOTE 1)	MATERIAL CATEGORY	CATALYST AND/OR PROMOTER (NOTE 2)	REINFORCEMENT	MINIMUM GEL TIME AT 76°F (MINUTES)	MATERIAL ABSORPTION DEPTH (INCHES)		CURE TIME (MINUTES)		COST (CENTS PER POUND) (NOTE 3)	VISCOSITY (CENTIPOISE) AT 75-80°F	SPECIFIC GRAVITY
					DRY SAND	10% WET SAND	DRY SAND	10% WET SAND			
1	POLYESTER	2% BPO PASTE, 2% DMA - STYRENE (50-50 MIXTURE)	NONE	20	1/4 TO 3/8	1/4 TO 3/8	25	30	20.4	400 TO 600	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)
2	POLYESTER	2% BPO PASTE, 2% DMA - STYRENE (50-50 MIXTURE)	NONE	20	1/4 TO 3/8	1/4 TO 3/8	25	40	24.4	400 TO 600	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)
3	POLYESTER	2% BPO PASTE, 2% DMA - STYRENE (50-50 MIXTURE)	NONE	4	1/4	1/8 TO 3/8	15	25	26	400 TO 600	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)
4	POLYESTER	2% BPO PASTE, 2% DMA - STYRENE (50-50 MIXTURE)	NONE	8	1/4	1/4 TO 3/8	15	20	43	1000	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)
5	POLYESTER	2% BPO PASTE, 2% DMA - STYRENE (50-50 MIXTURE)	NONE	11	1/4 TO 3/8	1/4 TO 1/2	20	30	20.4	1000	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)
6	POLYESTER	2% BPO PASTE, 2% DMA - STYRENE (50-50 MIXTURE) + 20% STYRENE	NONE	8	3/8 TO 1/2	1/2	15	20	35	1500	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)
7	POLYESTER	2% BPO PASTE, 2% DMA - STYRENE (50-50 MIXTURE) +20% STYRENE	NONE	20	1/4 TO 3/8	1/16	25	30	20.4	400 TO 600	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)
8	POLYESTER	2% BPO PASTE, 2% DMA - STYRENE (50-50 MIXTURE) + 20% STYRENE	NONE	8	1/4	1/4 TO 3/8	15	20	43	1000	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)
9	POLYESTER	2% BPO PASTE, 2% DMA - STYRENE (80-20 MIXTURE)	NONE	15	1/4 TO 3/8	1/4 TO 3/8	25	35	UNK	[illegible]	UNK
10	POLYESTER	1% CATALYST 1% PROMOTER	NONE	2	1/4	3/8 TO 1/2	15	25	22.1	300 TO 500	1.10 TO 1.12 (UNK)
11	POLYESTER	2% BPO PASTE, 2% DMA - STYRENE (50-50 MIXTURE)	NONE	7	3/8 TO 1/2	3/8 TO 1/2	9	20	23.5	400	1.22 (UNK)
12	POLYESTER	2% BPO PASTE, 2% DMA - STYRENE (50-50 MIXTURE)	CHPD FBRGLAS 2-5% BY WT	11	1/4 TO 3/8	1/4 TO 1/2	20	30	20.4	1000	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)
13	POLYESTER	2% BPO PASTE, 2% DMA - STYRENE (50-50 MIXTURE)	CHPD FBRGLAS 2-5% BY WT	20	1/4 TO 3/8	1/4 TO 3/8	25	30	20.4	400 TO 600	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)
14	POLYESTER	2% BPO PASTE, 2% DMA - STYRENE (50-50 MIXTURE)	CHPD FBRGLAS 10% BY WT	4	1/4	1/8 TO 3/8	15	25	26	400 TO 600	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)
15	POLYESTER	2% BPO PASTE, 2% DMA - STYRENE (50-50 MIXTURE)	NONE	40	3/8 TO 1/2	3/8 TO 1/2	90	>240	UNK	415	1.02 LIQUID
16	POLYESTER	2% BPO PASTE, 2% DMA - STYRENE (50-50 MIXTURE)	NONE	7	1/4 TO 3/8	1/4 TO 3/8	10	20	UNK	425 TO 525	1.1[illegible] LIQUID
17	POLYESTER	2% BPO PASTE, 2% DMA- STYRENE (50-50 MIXTURE)	NONE	3	1/4	3/8	10	15	25	2250	1.14 (LIQUID RESIN) 1.20 (CURED RESIN)
18	POLYESTER	2% BPO PASTE, 2% DMA - STYRENE (50-50 MIXTURE)	CHPD FBRGLAS 2 - 5% BY WT	8	1/4	1/4 TO 3/8	15	20	43	1000	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)
19	POLYESTER	2% BPO PASTE, 2% DMA - STYRENE (50-50 MIXTURE)	CHPD FBRGLAS 2-5% BY WT	8	3/8 TO 1/2	1/2	15	20	35	1500	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)
20	POLYESTER	2% BPO PASTE, 2% DMA- STYRENE PLUS 50% EXTENDER	NONE				> 240		17	UNK	UNK
21	POLYESTER	2% BPO PASTE, 2% DMA STYRENE	NONE	60	1/2 TO 3/4		> 240		UNK	UNK	UNK
22	POLYESTER	50g RESINS, 20g STYRENE, 20g H_2O, 0.5g BENZOYL PEROXIDE, 0.25g DIMETHYL ANALINE	NONE	210	NO BOND		> 240		UNK	UNK	UNK
23	POLYESTER	2% BPO PASTE, 1% DMA	ROCKWOOL 5% BY WT.	8	1/8		25		34	1500	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)
24	POLYESTER	2% BPO PASTE, 2% DMA- STYRENE (50-50 MIXTURE)	NONE	>180	3/8 TO 1/2		>180		UNK	UNK	UNK
25	POLYESTER	2% BPO PASTE, 1% DMA	NONE	8	NONE	NONE	5 TO 10	5 TO 10	43	1000	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)
26	POLYESTER	2% BPO PASTE, 2.5% OF DMA - STYRENE (10-90 MIXTURE) PLUS 10% STYRENE	NONE	8	NONE	NONE	8	8	43	1000	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)
27	POLYESTER	2% BPO PASTE, 2% DMA- STYRENE (50-50 MIXTURE)	NONE	11	3/8 TO 1/2		20 TO 30		20.4	1000	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)

A

		PROPERTIES BEFORE CURING							PROPERTIES AFTER CURING			
% SAND	COST (CENTS PER POUND) (NOTE 3)	VISCOSITY (CENTIPOISE) AT 75-80 F	SPECIFIC GRAVITY	TOXICITY (NOTE 4)	SHELF LIFE (NOTE 5)	POT LIFE (NOTE 6)	STORAGE LIMITATION	CORROSIVE EFFECT	WATER ABSORBTION (IN 24 HOURS)	FLAMMABILITY (NOTE 7)	COEFFICIENT OF LINEAR EXPANSION (INCH PER INCH PER F X 10^{-6})	COLOR
30	20.4	400 TO 600	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)	NOT CONSIDERED TOXIC	6 MOS. AT 70 F.	VARIABLE-NOT CRITICAL	HIGHER TEMP. SHORTENS LIFE	NONE	1.2% AT 77 F	BURNS	50-60 AS CAST 14-18 MAT LAYUP	TURNS YELLOW IN SUNLIGHT
40	24.4	400 TO 600	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)	NOT CONSIDERED TOXIC	6 MOS. AT 70 F.	VARIABLE-NOT CRITICAL	HIGHER TEMP. SHORTENS LIFE	NONE	1.2% AT 77 F	BURNS	50-60 AS CAST 14-18 MAT LAYUP	TURNS YELLOW IN SUNLIGHT
25	26	400 TO 600	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)	NOT CONSIDERED TOXIC	6 MOS. AT 70 F.	VARIABLE-NOT CRITICAL	HIGHER TEMP. SHORTENS LIFE	NONE	1.2% AT 77 F	BURNS	50-60 AS CAST 14-18 MAT LAYUP	TURNS YELLOW IN SUNLIGHT
20	43	1000	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)	NOT CONSIDERED TOXIC	6 MOS. AT 70 F.	VARIABLE-NOT CRITICAL	HIGHER TEMP. SHORTENS LIFE	NONE	1.2% AT 77 F	BURNS	50-60 AS CAST 14-18 MAT LAYUP	TURNS YELLOW IN SUNLIGHT
30	20.4	1000	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)	NOT CONSIDERED TOXIC	6 MOS. AT 70 F.	VARIABLE-NOT CRITICAL	HIGHER TEMP. SHORTENS LIFE	NONE	1.2% AT 77 F	BURNS	50-60 AS CAST 14-18 MAT LAYUP	TURNS YELLOW IN SUNLIGHT
20	35	1500	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)	NOT CONSIDERED TOXIC	6 MOS. AT 70 F.	VARIABLE-NOT CRITICAL	HIGHER TEMP. SHORTENS LIFE	NONE	1.2% AT 77 F	BURNS	50-60 AS CAST 14-18 MAT LAYUP	TURNS YELLOW IN SUNLIGHT
30	20.4	400 TO 600	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)	NOT CONSIDERED TOXIC	6 MOS AT 70 F	VARIABLE-NOT CRITICAL	HIGHER TEMP. SHORTENS LIFE	NONE	1.2% AT 77 F	BURNS	50-60 AS CAST 14-18 MAT LAYUP	TURNS YELLOW IN SUNLIGHT
20	43	1000	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)	NOT CONSIDERED TOXIC	6 MOS. AT 70 F	VARIABLE-NOT CRITICAL	HIGHER TEMP. SHORTENS LIFE	NONE	1.2% AT 77 F	BURNS	50-60 AS CAST 14-18 MAT LAYUP	TURNS YELLOW IN SUNLIGHT
35	UNK	325	UNK	UNK	UNK	UNK	UNK	UNK	UNK	UNK	UNK	BLUE-GREY
25	22.1	300 TO 500	1.10 TO 1.12 (UNK)	UNK	12 MOS AT 77 F. IN DARK	30 SEC. TO SEVERAL HOURS	UNK	UNK	UNK	BURNS	UNK	PALE AMBER
20	23.5	400	1.22 (UNK)	MODERATE TOXIC	>4 MOS. IN DARK	VARIABLE-NOT CRITICAL	CLOSED CONTAINER, COOL, DARK AREA	NONE	0.1% AT (UNK)	BURNS	45 AS CAST	CLEAR
40	20.4	1000	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)	NOT CONSIDERED TOXIC	6 MOS AT 70 F	VARIABLE-NOT CRITICAL	HIGHER TEMP. SHORTENS LIFE	NONE	1.2% AT 77 F	BURNS	50-60 AS CAST 14-18 MAT LAYUP	TURNS YELLOW IN SUNLIGHT
30	20.4	400 TO 600	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)	NOT CONSIDERED TOXIC	6 MOS AT 70 F	VARIABLE-NOT CRITICAL	HIGHER TEMP. SHORTENS LIFE	NONE	1.2% AT 77 F	BURNS	50-60 AS CAST 14-18 MAT LAYUP	TURNS YELLOW IN SUNLIGHT
25	26	400 TO 600	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)	NOT CONSIDERED TOXIC	6 MOS AT 70 F	VARIABLE NOT CRITICAL	HIGHER TEMP. SHORTENS LIFE	NONE	1.2% AT 77 F	BURNS	50-60 AS CAST 14-18 MAT LAYUP	TURNS YELLOW IN SUNLIGHT
240	UNK	415	1.02 LIQUID	UNK	UNK	UNK	UNK	UNK	UNK	UNK	UNK	UNK
70	UNK	425 TO 525	1.11 LIQUID	UNK	UNK	UNK	UNK	UNK	UNK	UNK	UNK	LIGHT PURPLE
5	25	2250	1.14 (LIQUID RESIN) 1.20 (CURED RESIN)	UNK	6 MOS AT 70 F	VARIABLE-NOT CRITICAL	HIGHER TEMP. SHORTENS LIFE	NONE	1.2% AT 77 F	BURNS	50-60 AS CAST 14-18 MAT LAYUP	TURNS YELLOW IN SUNLIGHT
0	43	1000	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)	NOT CONSIDERED TOXIC	6 MOS AT 70 F	VARIABLE-NOT CRITICAL	HIGHER TEMP. SHORTENS LIFE	NONE	1.2% AT 77 F	BURNS	50-60 AS CAST 14-18 MAT LAYUP	TURNS YELLOW IN SUNLIGHT
0	35	1500	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)	NOT CONSIDERED TOXIC	6 MOS AT 70 F	VARIABLE-NOT CRITICAL	HIGHER TEMP. SHORTENS LIFE	NONE	1.2% AT 77 F	BURNS	50-60 AS CAST 14-18 MAT LAYUP	TURNS YELLOW IN SUNLIGHT
	17	UNK	UNK	NOT CONSIDERED TOXIC	UNK	UNK	UNK	UNK	UNK	UNK	UNK	UNK
	UNK	UNK	UNK	NOT CONSIDERED TOXIC	UNK	UNK	UNK	UNK	UNK	UNK	UNK	UNK
	UNK	UNK	UNK	NONE TOXIC	UNK	UNK	UNK	UNK	UNK	UNK	UNK	UNK
	34	1500	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)	NOT CONSIDERED TOXIC	6 MOS AT 70 F	VARIABLE-NOT CRITICAL	HIGHER TEMP. SHORTENS LIFE	NONE	1.2% AT 77 F	BURNS	50-60 AS CAST 14-18 MAT LAYUP	TURNS YELLOW IN SUNLIGHT
	UNK	UNK	UNK	NONE TOXIC	UNK	UNK	UNK	UNK	UNK	UNK	UNK	UNK
10	43	1000	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)	NOT CONSIDERED TOXIC	6 MOS AT 70 F	VARIABLE-NOT CRITICAL	HIGHER TEMP. SHORTENS LIFE	NONE	1.2% AT 77 F	BURNS	50-60 AS CAST 14-18 MAT LAYUP	TURNS YELLOW IN SUNLIGHT
5	43	1000	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)	NOT CONSIDERED TOXIC	6 MOS AT 70 F	VARIABLE-NOT CRITICAL	HIGHER TEMP. SHORTENS LIFE	NONE	1.2% AT 77 F	BURNS	50-60 AS CAST 14-18 MAT LAYUP	TURNS YELLOW IN SUNLIGHT
	20.4	1000	1.1 (LIQUID RESIN) 1.2 (CURED RESIN)	NOT CONSIDERED TOXIC	6 MOS AT 70 F	VARIABLE-NOT CRITICAL	HIGHER TEMP. SHORTENS LIFE	NONE	1.2% AT 77 F	BURNS	50-60 AS CAST 14-18 MAT LAYUP	TURNS YELLOW IN SUNLIGHT

NOTE 1: THE FOLLOWING SPECIMENS WERE FORMULATED FROM THE SAME POLYESTER RESINS:
1, 7, & 13
3 & 14
4, 9, 18, 25 & 26
5, 12, & 27
6, 19, & 23
11 & 20
16 & 21

NOTE 2: DEFINITIONS: CATALYST BPO: 50% BENZOY
OXIDE, 50% TRICRESOLPHOS
PASTE
PROMOTER DMA: DIMETHYLA

NOTE 3: COST BASED ON MINIMUM PROCUREMENT O
APPROXIMATELY 20,000 POUNDS

B

		RESISTANCE TO PETROLEUM PRODUCTS						
	SURFACE SMOOTHNESS	SKYDROL	JP-4	OIL	KEROSENE	GASOLINE	OPERATOR PERSONNEL TRAINING REQUIREMENT	REMARKS
OW T	SMOOTH - CONTROLLABLE	FAIR	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEMI-SKILLED	FAIR STRENGTH
OW T	SMOOTH - CONTROLLABLE	GOOD	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEMI-SKILLED	FAIR STRENGTH
OW T	SMOOTH - CONTROLLABLE	GOOD	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEMI-SKILLED	LOW STRENGTH
OW T	SMOOTH - CONTROLLABLE	GOOD	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEMI-SKILLED	LOW STRENGTH
OW T	SMOOTH - CONTROLLABLE	FAIR	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEMI-SKILLED	LOW STRENGTH
OW T	SMOOTH - CONTROLLABLE	FAIR	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEMI-SKILLED	GOOD STRENGTH
OW T	SMOOTH	FAIR	UNK	EXCELLENT	UNK	EXCELLENT	SEMI-SKILLED	SPRAYED SAMPLE, NO STRENGTH TEST
OW T	SMOOTH	GOOD	GOOD	EXCELLENT	EXCELLENT	UNK	SEMI-SKILLED	DIFFICULT TO SPRAY MATERIAL, VISCOSITY TOO HIGH, SPRAYED SAMPLE, NO STRENGTH TEST
	SMOOTH	UNK	UNK	UNK	UNK	UNK	SEMI-SKILLED	APPEARS SATISFACTORY, BASED ON PRELIMINARY INFORMATION, FAIR STRENGTH
R	SMOOTH	UNK	UNK	UNK	UNK	UNK	SEMI-SKILLED	CATALYST WAS CHANGED FOR 10% WET SAND TEST TO 2% BPO, 2% DMA - STYRENE (50-50 MIXTURE) FAIR STRENGTH
	CONTROLLABLE	UNK	GOOD	GOOD	GOOD	GOOD	SEMI-SKILLED	GOOD STRENGTH
OW T	SLIGHTLY ROUGH	FAIR	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEMI-SKILLED	FAIR STRENGTH - FIBERGLASS USED TO OBSERVE SURFACE ROUGHNESS & RESIN ABSORPTION, SAND ABSORBS RESIN AS READILY AS FIBERGLASS
OW T	SLIGHTLY ROUGH	FAIR	GOOD	EXCELLENT	EXCELLENT	EXC[illegible]	[illegible]LLED	FAIR STRENGTH - FIBERGLASS USED TO OBSERVE SURFACE ROUGHNESS & RESIN ABSORPTION, SAND ABSORBS RESIN AS READILY AS FIBERGLASS
OW T	SLIGHTLY ROUGH	GOOD	GOOD	EXCELLENT	EXCELLENT	EXCELLE[illegible]	[illegible]SKILLED	FAIR STRENGTH - FIBERGLASS USED TO OBSERVE SURFACE ROUGHNESS & RESIN ABSORPTION, SAND ABSORBS RESIN AS READILY AS FIBERGLASS
	SMOOTH	UNK	UNK	UNK	UNK	UNK	SEMI-SKILLED	SLOW CURING, NOT ACCEPTABLE
PLE	SMOOTH	UNK	UNK	UNK	UNK	UNK	SEMI-SKILLED	FAIR STRENGTH
OW T	SMOOTH	UNK	UNK	UNK	UNK	UNK	SEMI-SKILLED	FAIR STRENGTH
OW T	SLIGHTLY ROUGH	GOOD	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEMI-SKILLED	FAIR STRENGTH - FIBERGLASS USED TO OBSERVE SURFACE ROUGHNESS & RESIN ABSORPTION, SAND ABSORBS RESIN AS READILY AS FIBERGLASS
OW T	SLIGHTLY ROUGH	FAIR	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEMI-SKILLED	GOOD STRENGTH - FIBERGLASS USED TO OBSERVE SURFACE ROUGHNESS & RESIN ABSORPTION, SAND ABSORBS RESIN AS READILY AS FIBERGLASS
	UNK	UNK	UNK	UNK	UNK	UNK	SEMI-SKILLED	NO CURE IN 4 HRS - PETROLEUM EXTENDER ADDED (50% POLYESTER, 50% EXTENDER)
	UNK	UNK	UNK	UNK	UNK	UNK	SEMI-SKILLED	NO CURE IN 4 HRS, MIXTURE OF 75% RIGID POLYESTER AND 25% FLEXIBLE POLYESTER
	UNK	UNK	UNK	UNK	UNK	UNK	UNK	NO GEL IN MORE THAN 3 HRS, NO STRENGTH
LOW HT	SLIGHTLY ROUGH	FAIR	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEMI-SKILLED	0.4 LB/FT^2 COVERAGE - SPECIMEN COVERAGE LIGHT, ROCKWOOL STRENGTH NOT GOOD IN SHEAR OR TENSILE, LOW STRENGTH, ROCKWOOL DOES NOT ABSORB RESIN READILY
	UNK	UNK	UNK	UNK	UNK	UNK	UNK	WAS ABLE TO PENETRATE GEL TEST SPECIMEN WITH SPATULA AT END OF 3 HRS. CURE TIME IN DRY SAND MORE THAN 3 HRS
LOW HT	SMOOTH	GOOD	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEMI-SKILLED	APPLIED MAT'L ON BENTONITE (DRY & MOIST), SURFACE COAT FORMED IN 10 MIN, BUT NO ABSORBTION OF MAT'L INTO BENTONITE OCCURRED (NOTE 8)
LOW HT	SMOOTH	FAIR	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEMI-SKILLED	SPRAYED MAT'L ON BENTONITE (DRY & 30% MOISTURE), A LOT OF BENTONITE BLOWN AWAY DURING SPRAYING - NO MAT'L ABSORBTION NOTED (NOTE 8)
LOW HT	ROUGH	FAIR	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEMI-SKILLED	APPLIED MAT'L ON COARSE SAND & PEBBLES 3/8 IN. - 1/2 IN. ABSORBTION DEPTH OF MAT'L INTO SAND & PEBBLES, NO STRENGTH TEST, CONDUCTED TO DETERMINE ADHESION OF POLYESTER TO COARSE SAND AND GRAVEL

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NOTE 4: THE POLYESTER RESIN IS SLIGHTLY TOXIC ONLY WHEN INGESTED. THE PROMOTER AND CATALYST ARE MODERATELY TOXIC BY INGESTION, INHALATION, AND SKIN ABSORBTION.

NOTE 5: SHELF LIFE INFORMATION IS BASED ON VENDOR GUARANTEES CONSIDERING THE USE OF COMMERCIALLY AVAILABLE MATERIAL. FOR ADDITIONAL INFORMATION ON PROJECTED SHELF LIFE FOR MILI-

NOTE 6: USEABLE TIME PERIOD FOR PREMIXED COMPONENTS PRIOR TO APPLICATION

NOTE 7: ALL POLYESTERS BURN, BUT ADDITIVES SUCH AS FIBERGLASS AND INHIBITORS CAN MAKE THEM NONFLAMMABLE.

NOTE 8: NO STRENGTH TEST. TEST CONDUCTED TO DETERMINE ADHESION OF POLYESTER TO BENTONITE CLAY.

LEGEND:

☒ UNACCOMPLISHED

UNK: UNKNOWN

Fig. A-1 Material Characteristics (Polyester Family)

SPECIMEN NUMBER (NOTE 1)	MATERIAL CATEGORY	HARDENER (NOTE 2)	REINFORCEMENT	MINIMUM GEL TIME AT 76 F (MINUTES)	MATERIAL ABSORBTION DEPTH (INCHES)		CURE TIME (MINUTES)		COST (CENTS PER POUND) (NOTE 3)			
					DRY SAND	10% WET SAND	DRY SAND	10% WET SAND		VISCOSITY (CENTIPOISED AT 75-80 F	SPECIFIC GRAVITY	TOXICITY (NOTE 4)
28	EPOXY	25% CURING AGENT	NONE	32	1/4	1/4 TO 3/8	105	135	68.6	500 TO 700	1.13	CAUTION REQUIRED
29	EPOXY	10% DTA	NONE	60	1/2 TO 3/4	3/4 TO 1	60	90	106	90 TO 150	1.2	CAUTION REQUIRED
30	EPOXY	50% HARDENER A	NONE	>240					>80	UNK	UNK	CAUTION REQUIRED
31	EPOXY	66% HARDENER A	NONE	>240					>80	UNK	UNK	CAUTION REQUIRED
32	EPOXY	50% HARDENER	NONE	8	[illegible]	3/8	60	75	68	10,000 TO 19,000	1.15 TO 1.17	CAUTION REQUIRED
33	EPOXY	50% HARDENER	NONE	5	3/8 [illegible] 1/2	1/2	60	90	56	500 TO 1000	1.10 TO 1.15	CAUTION REQUIRED
34	EPOXY	25% HARDENER + 25% EXTENDER	NONE	NONE					55	UNK	UNK	CAUTION REQUIRED
35	EPOXY	25% HARDENER + 25% EXTENDER	NONE	NONE					55	[illegible]	UNK	CAUTION REQUIRED
36	EPOXY	50% HARDENER	NONE	>180					80	40,000 TO 50,000	1.05 TO 1.10	CAUTION REQUIRED
37	EPOXY	18% HARDENER	NONE	>180					80	UNK	UNK	CAUTION REQUIRED
38	EPOXY	34% CURING AGENT	NONE	32	NONE	NONE	30	30	70.2	500 TO 700	1.13	CAUTION REQUIRED

A

	PROPERTIES BEFORE CURING				PROPERTIES AFTER CURING					RESISTANCE TO PETROLEUM PRODUCTS (NOTE 8)					
ITY 1)	SHELF LIFE (NOTE 5)	POT LIFE (NOTE 6)	STORAGE LIMITATION	CORROSIVE EFFECT	WATER ABSORBTION (IN 24 HOURS)	FLAMMABILITY (NOTE 7)	COEFFICIENT OF LINEAR EXPANSION (INCH PER INCH PER F X 10^{-6})	COLOR	SURFACE SMOOTHNESS	SKYDROL	JP-4	OIL	KEROSENE	GASOLINE	OPERA PERSO TRAIN REQUI
ON RED	INFINITE	VARIABLE - NOT CRITICAL	CLOSED CONTAINER	NONE	0.1% AT 77 F	BURNS	1.2 FG MATTING 5.1 AS CAST	SLIGHT YELLOWING	SMOOTH	EXCELLENT	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEM SKI
ON RED	INFINITE	VARIABLE - NOT CRITICAL	CLOSED CONTAINER	NONE	0.1% AT 77 F	BURNS	1.2 FG MATTING 5.1 AS CAST	SLIGHT YELLOWING	SMOOTH	EXCELLENT	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEM SKI
ON RED	INFINITE	VARIABLE - NOT CRITICAL	CLOSED CONTAINER	NONE	0.1% AT 77 F	BURNS	1.2 FG MATTING 5.1 AS CAST	SLIGHT YELLOWING	SMOOTH	EXCELLENT	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEM SKI
ON RED	INFINITE	VARIABLE - NOT CRITICAL	CLOSED CONTAINER	NONE	0.1% AT 77 F	BURNS	1.2 FG MATTING 5.1 AS CAST	SLIGHT YELLOWING	SMOOTH	EXCELLENT	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEM SKI
ON RED	INFINITE	VARIABLE - NOT CRITICAL	CLOSED CONTAINER	NONE	0.1% AT 77 F	BURNS	1.2 FG MATTING 5.1 AS CAST	SLIGHT YELLOWING	SMOOTH	EXCELLENT	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEM SKI
ON RED	INFINITE	VARIABLE - NOT CRITICAL	CLOSED CONTAINER	NONE	0.1% AT 77 F	BURNS	1.2 FG MATTING 5.1 AS CAST	SLIGHT YELLOWING	SMOOTH	EXCELLENT	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SE SKI
ON RED	INFINITE	VARIABLE - NOT CRITICAL	CLOSED CONTAINER	NONE	0.1% AT 77 F	BURNS	UNK	YELLOW	UNK	UNK	UNK	UNK	UNK	UNK	SE SK
ON RED	INFINITE	VARIABLE - NOT CRITICAL	CLOSED CONTAINER	NONE	0.1% AT 77 F	BURNS	UNK	YELLOW	UNK	UNK	UNK	UNK	UNK	UNK	SE SK
ON RED	INFINITE	VARIABLE - NOT CRITICAL	CLOSED CONTAINER	NONE	0.1% AT 77 F	BURNS	UNK	SLIGHT YELLOWING	SMOOTH	UNK	UNK	UNK	UNK	UNK	SE SK
ON RED	INFINITE	VARIABLE - NOT CRITICAL	CLOSED CONTAINER	NONE	0.1% AT 77 F	BURNS	UNK	SLIGHT YELLOWING	SMOOTH	UNK	UNK	UNK	UNK	UNK	SE SK
ON RED	INFINITE	VARIABLE - NOT CRITICAL	CLOSED CONTAINER	NONE	0.1% AT 77 F	BURNS	1.2 FG MATTING 5.1 AS CAST	SLIGHT YELLOWING	SMOOTH	EXCELLENT	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SE SK

NOTE 1: THE FOLLOWING SPECIMENS WERE FORMULATED FROM THE SAME EPOXY COMPOUNDS:
28 & 38 — 33, 34 & 35
30 & 31 — 36 & 37

NOTE 2: MANY OF THE HARDENING AGENTS ARE KNOWN ONLY BY THEIR COMMERCIAL NAME.

DEFINITIONS: DTA: DIETHYLENE - TRIAMINE

NOTE 3: COST IS BASED ON MINIMUM PROCUREMEN OF APPROXIMATELY 20,000 POUNDS. SOME EPOXIES ARE AVAILABLE IN TANK LOTS, MINIMUM 30,000 POUNDS.

NOTE 4: PRECAUTION MUST BE TAKEN IN HANDLING EPOXIES, BECAUSE OF POSSIBLE SKIN IRRITATION.

NOTE 5: EPOXY RESINS AND HARDENERS MAY BE ST INDEFINITELY IN CLOSED CONTAINERS UND IN ALL ENVIRONMENTAL CONDITIONS EXCEP FREEZING TEMPERATURES.

B

Fig. A-2 Materia

		RESISTANCE TO PETROLEUM PRODUCTS (NOTE 8)						
	SURFACE SMOOTHNESS	SKYDROL	JP-4	OIL	KEROSENE	GASOLINE	OPERATOR PERSONNEL TRAINING REQUIREMENT	REMARKS
NG	SMOOTH	EXCELLENT	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEMI-SKILLED	FAIR STRENGTH
NG	SMOOTH	EXCELLENT	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEMI-SKILLED	NOT ACCEPTABLE, LOW STRENGTH
NG	SMOOTH	EXCELLENT	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEMI-SKILLED	NO CURE IN 4 HRS
NG	SMOOTH	EXCELLENT	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEMI-SKILLED	NO CURE IN 4 HRS
NG	SMOOTH	EXCELLENT	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEMI-SKILLED	FAIR STRENGTH
NG	SMOOTH	EXCELLENT	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEMI-SKILLED	GOOD STRENGTH
	UNK	UNK	UNK	UNK	UNK	UNK	SEMI-SKILLED	NO CURE
	UNK	UNK	UNK	UNK	UNK	UNK	SEMI-SKILLED	NO CURE
NG	SMOOTH	UNK	UNK	UNK	UNK	UNK	SEMI-SKILLED	NO CURE IN 3 HRS
NG	SMOOTH	UNK	UNK	UNK	UNK	UNK	SEMI-SKILLED	NO CURE IN 3 HRS
NG	SMOOTH	EXCELLENT	GOOD	EXCELLENT	EXCELLENT	EXCELLENT	SEMI-SKILLED	MAT'L. APPLIED TO BENTONITE WET (10%, 20%, & 30% MOISTURE CONTENT) & DRY. NO ABSORBTION NOTED. SURFACE COAT FORMED IN 30 MIN. NO STRENGTH TEST. TEST CONDUCTED TO DETERMINE ADHESION OF EPOXY TO BENTONITE CLAY

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NOTE 3: COST IS BASED ON MINIMUM PROCUREMENT OF APPROXIMATELY 20,000 POUNDS. SOME EPOXIES ARE AVAILABLE IN TANK LOTS, MINIMUM 30,000 POUNDS.

NOTE 4: PRECAUTION MUST BE TAKEN IN HANDLING EPOXIES, BECAUSE OF POSSIBLE SKIN IRRITATION.

NOTE 5: EPOXY RESINS AND HARDENERS MAY BE STORED INDEFINITELY IN CLOSED CONTAINERS UNDER IN ALL ENVIRONMENTAL CONDITIONS EXCEPT FREEZING TEMPERATURES.

NOTE 6: POT LIFE IS THE USEABLE TIME PERIOD FOR PRE-MIXED COMPONENTS PRIOR TO APPLICATION.

NOTE 7: ALL EPOXIES BURN, BUT ADDITIVES SUCH AS FIBERGLASS AND INHIBITORS CAN MAKE IT NONFLAMMABLE.

LEGEND:

-	UNACCOMPLISHED

UNK: UNKNOWN

Fig. A-2 Material Characteristics (Epoxy Family)

C

SPECIMEN NUMBER (NOTE 1)	MATERIAL CATEGORY	CATALYST (NOTE 2)	REINFORCEMENT	MINIMUM GEL TIME AT 76 F (MINUTES)	MATERIAL ABSORBTION DEPTH (INCHES)		CURE TIME (MINUTES)		COST (CENTS PER POUND) (NOTE 3)	PR		
					DRY SAND	10% WET SAND	DRY SAND	10% WET SAND		VISCOSITY (CENTIPOISE) AT 75-80 F	SPECIFIC GRAVITY	TOXICITY (NOTE 4)
39	POLYURETHANE (NON-FOAM)	MOISTURE CURING	NONE	NONE					UNK	370 TO 1800	1.06	CAUTION REQUIRE
40	POLYURETHANE (NON-FOAM)	40% PART B HARDENER	NONE	150					80	8000	1.06	CAUTION REQUIRE
41	POLYURETHANE FOAM	47% COMPONENT C	NONE	10	NONE	NONE	10	10	40 TO 60	UNK	1.5 TO 2.2	CAUTION REQUIRE
42	POLYURETHANE FOAM	45% COMPONENT C	NONE	5	NONE	NONE	5	5	40 TO 60	UNK	1.5 TO 2.2	CAUTION REQUIRE
43	POLYURETHANE FOAM	50% COMPONENT C	NONE	A FEW SECONDS	NONE	NONE			40 TO 60	UNK	1.5 TO 2.2	CAUTION REQUIRE
44	POLYURETHANE FOAM	25% COMPONENT C	NONE	NONE	NONE	NONE			40 TO 60	UNK	1.5 TO 2.2	CAUTION REQUIRE
45	POLYURETHANE FOAM	51% COMPONENT C	NONE	8	NONE	NONE	8	8	40 TO 60	UNK	1.5 TO 2.2	CAUTION REQUIRE
46	POLYURETHANE FOAM	120g RESIN, 0.1g TMBDA, (MIXED 80g QUADROL, 1.5g SA TOGETHER)	NONE	4	NONE	NONE	4	4	40 TO 60	UNK	1.5 TO 2.2	CAUTION REQUIRE
47	POLYURETHANE FOAM LAMINATE	COMBINATION OF #41 AND #46 FORMULATIONS	PAPER CORE	10	NONE	NONE	10	10	40 TO 60	UNK	1.5 TO 2.2	CAUTION REQUIRE
48	POLYURETHANE FOAM	13.5% COMPONENT C	NONE	A FEW SECONDS	NONE	NONE			40 TO 60	UNK	1.5 TO 2.2	CAUTION REQUIRE
49	POLYURETHANE FOAM	14% COMPONENT C	NONE	3	NONE	NONE	3	3	40 TO 60	UNK	1.5 TO 2.2	CAUTION REQUIRE
50	POLYURETHANE FOAM LAMINATE	34% COMPONENT C 24% COMPONENT R	NONE	3	NONE	NONE	3	3	40 TO 60	UNK	1.5 TO 2.2	CAUTION REQUIRE

4

CURE TIME (MINUTES)		COST (CENTS PER POUND) (NOTE 3)	PROPERTIES BEFORE CURING							PROPERTIES AFTER CURING				
DRY SAND	10% WET SAND		VISCOSITY (CENTIPOISE) AT 75-80 F	SPECIFIC GRAVITY	TOXICITY (NOTE 4)	SHELF LIFE (NOTE 5)	POT LIFE (NOTE 6)	STORAGE LIMITATION	CORROSIVE EFFECT	WATER ABSORBTION (% IN 24 HOURS)	FLAMMABILITY (NOTE 7)	COEFFICIENT OF LINEAR EXPANSION (INCH PER INCH PER F X 10^{-6})	COLOR	S
		UNK	370 TO 1800	1.06	CAUTION REQUIRED	6 TO 18 MOS	ADJUSTABLE	MIN 45 F MAX 110 F	NONE	LOW	BURNS	UNK	YELLOWS WITH AGE	
		80	8000	1.06	CAUTION REQUIRED	6 TO 18 MOS	ADJUSTABLE	MIN 45 F MAX 110 F	NONE	LOW	BURNS	UNK	YELLOWS WITH AGE	
10	10	40 TO 60	UNK	1.5 TO 2.2	CAUTION REQUIRED	6 TO 18 MOS	ADJUSTABLE	MIN 45 F MAX 110 F	NONE	LOW	BURNS	UNK	YELLOWS WITH AGE	
5	5	40 TO 60	UNK	1.5 T[illegible] 2	CAUTION REQUIRED	6 TO 18 MOS	ADJUSTABLE	MIN 45 F MAX 110 F	NONE	LOW	BURNS	UNK	YELLOWS WITH AGE	
		40 TO 60	UNK	1.5 TO 2.2	CAUTION REQUIRED	6 TO 18 MOS	ADJUSTABLE	MIN 45 F MAX 110 F	NONE	LOW	BURNS	UNK	YELLOWS WITH AGE	
		40 TO 60	UNK	1.5 TO 2.2	CAUTION REQUIRED	6 TO 18 MOS	ADJUSTABLE	MIN 45 F MAX 110 F	NONE	LOW	BURNS	UNK	YELLOWS WITH AGE	
8	8	40 TO 60	UNK	1.5 TO 2.2	CAUTION REQUIRED	6 TO 18 MOS	ADJUSTABLE	MIN 45 F MAX 110 F	NONE	LOW	BURNS	UNK	YELLOWS WITH AGE	
4	4	40 TO 60	UNK	1.5 TO 2.2	CAUTION REQUIRED	6 TO 18 MOS	ADJUSTABLE	MIN 45 F MAX 110 F	NONE	LOW	BURNS	UNK	YELLOWS WITH AGE	
10	10	40 TO 60	UNK	1.5 TO 2.2	CAUTION REQUIRED	6 TO 18 MOS	ADJUSTABLE	MIN 45 F MAX 110 F	NONE	LOW	BURNS	UNK	YELLOWS WITH AGE	
		40 TO 60	UNK	1.5 TO 2.2	CAUTION REQUIRED	6 TO 18 MOS	ADJUSTABLE	MIN 45 F MAX 110 F	NONE	LOW	BURNS	UNK	YELLOWS WITH AGE	
3	3	40 TO 60	UNK	1.5 TO 2.2	CAUTION REQUIRED	6 TO 18 MOS	ADJUSTABLE	MIN 45 F MAX 110 F	NONE	LOW	BURNS	UNK	YELLOWS WITH AGE	
3	3	40 TO 60	UNK	1.5 TO 2.2	CAUTION REQUIRED	6 TO 18 MOS	ADJUSTABLE	MIN 45 F MAX 110 F	NONE	LOW	BURNS	UNK	YELLOWS WITH AGE	

NOTE 1: THE FOLLOWING SPECIMENS WERE FORMULATED FROM THE SAME POLYURETHANE COMPOUNDS
41, 45, & 47
4[illegible], & 44
49 & 50

NOTE 2: MANY CATALYTIC AGENTS ARE KNOWN ONLY BY THEIR COMMERCIAL NAME.
DEFINITIONS: SA: SURFACTIVE AGENT
TMBDA: TETRAMETHYLBUTANE DIAMINE

B

	RESISTANCE TO PETROLEUM PRODUCTS (NOTE 8)						
SURFACE SMOOTHNESS	SKYDROL	JP-4	OIL	KEROSENE	GASOLINE	OPERATOR PERSONNEL TRAINING REQUIREMENT	REMARKS
SMOOTH	GOOD	GOOD	GOOD	GOOD	GOOD	SEMI-SKILLED	NO CURE
SMOOTH	GOOD	GOOD	GOOD	GOOD	GOOD	SEMI-SKILLED	NO CURE IN 3 HRS
SMOOTH	GOOD	GOOD	GOOD	GOOD	GOOD	SEMI-SKILLED	FOAMED TO 1 1/2 TIMES ORIGINAL HEIGHT, GOOD STRENGTH
SMOOTH	GOOD	GOOD	GOOD	GOOD	GOOD	SEMI-SKILLED	FOAMED TO 1 1/2 TIMES ORIGINAL HEIGHT, NOT ACCEPTABLE, LIGHT DENSITY FOAM, NO STRENGTH TEST
SMOOTH	GOOD	GOOD	GOOD	GOOD	GOOD	SEMI-SKILLED	CURE TIME TOO SHORT, CAN NOT APPLY COMPOUND TO SURFACE
SMOOTH	GOOD	GOOD	GOOD	GOOD	GOOD	SEMI-SKILLED	INCOMPLETE FOAMING, INSUFFICIENT CATALYST, NO CURE
SMOOTH	GOOD	GOOD	GOOD	GOOD	GOOD	SEMI-SKILLED	FOAMED TO 3 TIMES ORIGINAL HT, DENSITY ABOUT 12 LB/FT^3 FOAM WAS FRIABLE, NO STRENGTH TEST
SMOOTH	GOOD	GOOD	GOOD	GOOD	GOOD	SEMI-SKILLED	CATALYST ADDED TO MIXTURE OF: 140g ISOCYANATE COMPOUND, 40g PHOSGARD C-22, 15g FREON 11, LOW STRENGTH
SMOOTH	GOOD	GOOD	GOOD	GOOD	GOOD	SEMI-SKILLED	TOP 0.7 IN, 22 LB/FT^3; MIDDLE 1 IN, 12 LB/FT^3; BOTTOM 0.4 IN, 22 LB/FT^3; TOO COMPLEX TO BUILD, NOT ACCEPTABLE, FAIR STRENGTH
SMOOTH	GOOD	GOOD	GOOD	GOOD	GOOD	SEMI-SKILLED	SYSTEM FOAMS TOO FAST TO OBTAIN UNIFORMLY FILLED CORE SECTIONS. DENSITY TOO LIGHT, NO STRENGTH TEST
SMOOTH	GOOD	GOOD	GOOD	GOOD	GOOD	SEMI-SKILLED	YIELDED 18 LB/FT^3 DENSITY FOAM, GOOD STRENGTH
SMOOTH	GOOD	GOOD	GOOD	GOOD	GOOD	SEMI-SKILLED	1 IN/2 IN/1 IN LAMINATED PANEL, 18 LB/FT^3/4 LB/FT^3/18 LB/FT^3, FAIR STRENGTH, TOO COMPLEX, NOT ACCEPTABLE

ATED
DS

Y BY

ANE

NOTE 3: COST IS BASED ON MINIMUM PROCUREMENT OF APPROXIMATELY 20,000 POUNDS.

NOTE 4: PRECAUTION MUST BE TAKEN IN HANDLING POLYURETHANES, BECAUSE OF POSSIBLE LUNG IRRITATION.

NOTE 5: POLYURETHANE SHOULD BE STORED IN CLOSED CONTAINERS OF "A" COMPONENT AND "B" COMPONENT AT TEMPERATURES UP TO 140 F.

NOTE 6: POT LIFE IS USEABLE TIME PERIOD FOR PRE-MIXED COMPONENTS PRIOR TO APPLICATION.

NOTE 7: ALL POLYURETHANES BURN, BUT ADDITIVES SUCH AS FILLERS AND INHIBITORS CAN MAKE THEM NONFLAMMABLE.

NOTE 8: NORMALLY POLYURETHANE IS NOT AFFECTED BY PETROLEUM PRODUCTS.

LEGEND:

☒ UNACCOMPLISHED

UNK: UNKNOWN

C

Fig. A-3 Material Characteristics (Foam Family)

SPECIMEN NUMBER (NOTE 1)	MATERIAL CATEGORY	CATALYST (NOTE 2)	REINFORCEMENT	MINIMUM GEL TIME AT 76 F (MINUTES)	MATERIAL ABSORBTION DEPTH (INCHES)		CURE TIME (MINUTES)		COST (CENTS PER POUND) (NOTE 3)	VISCOSITY (CENTIPOISE) AT 75-80 F	SPECIFIC GRAVITY
					DRY SAND	10% WET SAND	DRY SAND	10% WET SAND			
51	CEMENT	NONE	NONE	30	NONE		60		16	POWDER	1.36
52	CEMENT	NONE	SAND 1:1 RATIO	30	NONE		30		16	POWDER	1.5
53	CEMENT	NONE	NONE	30	NONE		30		16	POWDER	1.36
54	CEMENT	NONE	NONE	4	NONE		10		UNK	POWDER	UNK
55	CEMENT	NONE	NONE	NO CURE					UNK	POWDER	UNK
56	CEMENT	NONE	NONE	10	NONE		45		UNK	POWDER	UNK
57	LATEX	ACTIVATOR 2%	NONE	NO CURE					UNK	600 TO 800	UNK
58	LATEX	2% MEK PEROXIDE, 2% CYCLODEX MANGANESE	NONE	> 240					UNK	200 TO 400	UNK
59	LATEX	2% MEK PEROXIDE, 2% CYCLODEX MANGANESE	NONE	> 240					UNK	200 TO 400	UNK
60	LATEX	2% CYCLODEX COBALT	NONE	> 240					UNK	200 TO 400	UNK
61	LATEX	30% EMULSION	NONE	NO CURE					UNK	200 TO 400	UNK
62	LATEX	2% CYCLODEX MANGANESE, 10% H_2SO_4	NONE	> 180					UNK	200 TO 400	UNK
63	BINDER	50% PART B	NONE	40	1/4 TO 1/2	1/4 TO 1/2	40	90	100	200 TO 400	UNK
64	BINDER	50% PART B, 20% MEK	NONE	>					UNK	PASTE	UNK
65	BINDER	4% CURING AGENT, 20% MEK	NONE	60		NONE		60	UNK	PASTE	UNK
66	BINDER	NONE	NONE	> 240					UNK	PASTE	UNK
67	BINDER	NONE	NONE	> 240					UNK	PASTE	UNK
68	BINDER	10% WATER	NONE	> 240					21	100 TO 200	UNK
69	BINDER	1% CATALYST	NONE	NO CURE					30	POWDER	UNK
70	BINDER	1% CATALYST	NONE	NO CURE					30	UNK	UNK
71	BINDER	.6% CATALYST	NONE	NO CURE					30	OIL	UNK
72	RESIN	40% WATER, 10% H_2SO_4	NONE	300		1/4	60	90	24	POWDER	UNK

A

PROPERTIES BEFORE CURING				PROPERTIES AFTER CURING						RESISTANCE TO PETROLEUM PRODUCTS				
TOXICITY	SHELF LIFE (NOTE 4)	POT LIFE (NOTE 5)	STORAGE LIMITATION	CORROSIVE EFFECT	WATER ABSORBTION (% IN 24 HOURS)	FLAMMABILITY	COEFFICIENT OF LINEAR EXPANSION (INCH PER INCH PER F X 10^{-6})	COLOR	SURFACE SMOOTHNESS	SKYDROL	JP-4	OIL	KEROSENE	GAS
NONE	INDEFINITE	5 MIN	KEEP DRY	NONE	LOW	NONE	NEGLIGIBLE	GREY	SMOOTH	UNK	UNK	UNK	UNK	U
NONE	INDEFINITE	5 MIN	KEEP DRY	NONE	LOW	NONE	NEGLIGIBLE	GREY	SMOOTH	UNK	UNK	UNK	UNK	U
NONE	INDEFINITE	5 MIN	KEEP DRY	NONE	LOW	NONE	NEGLIGIBLE	GREY	VERY SMOOTH	UNK	UNK	UNK	UNK	U
MODERATE	1 YEAR	UNK	KEEP DRY	UNK	UNK	NONE	UNK	GREY	SMOOTH	UNK	UNK	UNK	UNK	U
LOW	UNK	5 MIN	KEEP DRY	UNK	UNK	NONE	UNK	GREY	SMOOTH	UNK	UNK	UNK	UNK	U
LOW	UNK	5 MIN	KEEP DRY	UNK	UNK	NONE	UNK	GREY	SMOOTH	UNK	UNK	UNK	UNK	U
LOW	INDEFINITE	SEVERAL HOURS	CLOSED CONTAINER	UNK	UNK	BURNS	UNK	WHITE	UNK	UNK	UNK	UNK	UNK	U
LOW	INDEFINITE	> 3 HRS	CLOSED CONTAINER	UNK	UNK	BURNS	UNK	WHITE	UNK	UNK	UNK	UNK	UNK	U
LOW	INDEFINITE	> 3 HRS	CLOSED CONTAINER	UNK	UNK	BURNS	UNK	WHITE	UNK	UNK	UNK	UNK	UNK	U
LOW	INDEFINITE	> 3 HRS	CLOSED CONTAINER	UNK	UNK	BURNS	UNK	WHITE	UNK	UNK	UNK	UNK	UNK	U
LOW	INDEFINITE	> 3 HRS	CLOSED CONTAINER	UNK	UNK	BURNS	UNK	CREAM	UNK	UNK	UNK	UNK	UNK	U
LOW	INDEFINITE	> 3 HRS	CLOSED CONTAINER	UNK	UNK	BURNS	UNK	CREAM	UNK	UNK	UNK	UNK	UNK	U
MODERATE	INDEFINITE	40 MIN	CLOSED CONTAINER	NONE	NONE	BURNS	UNK	YELLOWS WITH AGE	UNK	UNK	UNK	UNK	UNK	U
MODERATE	UNK	4 HRS	CLOSED CONTAINER	NONE	NONE	BURNS	UNK	BLACK	UNK	UNK	UNK	UNK	UNK	U
MODERATE	UNK	1 HR	CLOSED CONTAINER	NONE	NONE	BURNS	UNK	BLACK	UNK	UNK	UNK	UNK	UNK	U
UNK	UNK	> 4 HRS	CLOSED CONTAINER	UNK	UNK	BURNS	UNK	DARK PURPLE	UNK	UNK	UNK	UNK	UNK	U
UNK	UNK	> 4 HRS	CLOSED CONTAINER	UNK	UNK	BURNS	UNK	DARK PURPLE	UNK	UNK	UNK	UNK	UNK	U
UNK	UNK	> 4 HRS	CLOSED CONTAINER	UNK	UNK	BURNS	UNK	CREAM	UNK	UNK	UNK	UNK	UNK	U
HIGH	UNK	UNK	CLOSED CONTAINER	UNK	UNK	BURNS	UNK	CLEAR	UNK	UNK	UNK	UNK	UNK	U
MODERATE	UNK	UNK	CLOSED CONTAINER	UNK	UNK	BURNS	UNK	CLEAR	UNK	UNK	UNK	UNK	UNK	U
HIGH	UNK	UNK	CLOSED CONTAINER	UNK	UNK	BURNS	UNK	BROWN	UNK	UNK	UNK	UNK	UNK	U
UNK	UNK	60 MIN	CLOSED CONTAINER	UNK	UNK	HARD TO IGNITE	UNK	WHITE	UNK	UNK	UNK	UNK	UNK	U

NOTE 1: THE FOLLOWING SPECIMENS WERE FORMULATED FROM THE SAME COMPOUNDS OR MIXTURES:
51, 52 & 53
55 & 56
58, 59, & 60
61 & 62

NOTE 2: MANY CATALYTIC AGENTS ARE KNOWN ONLY BY THEIR COMMERCIAL NAME.

DEFINITIONS: MEK: METHYLETHYLKETONE

NOTE 3: COST IS BASED ON MINIMUM PROCUREMENT OF APPROXIMATELY 20,000 POUNDS.

NOTE 4: TEMPERATURE TO BE ABOVE FREEZI COMPOUND AND NOT EXCEEDING 9

NOTE 5: POT LIFE IS USEABLE TIME PERIOD COMPONENTS PRIOR TO APPLICATIO

NOTE 6: WATER REQUIRED FOR MIXING MAY AVAILABLE AT HELICOPTER PAD SIT ESSITATING TRANSPORTATION OF V

Fig. A-4

B

SURFACE SMOOTHNESS	RESISTANCE TO PETROLEUM PRODUCTS: SKYDROL	JP-4	OIL	KEROSENE	GASOLINE	OPERATOR PERSONNEL TRAINING REQUIREMENT	REMARKS (NOTE 6)
SMOOTH	UNK	UNK	UNK	UNK	UNK	LOW – SKILLED	MIXED WITH 25% H_2O, 1/16 IN. SURFACE COAT, NOT SUFFICIENT THICKNESS FOR STRENGTH TEST
SMOOTH	UNK	UNK	UNK	UNK	UNK	LOW – SKILLED	MIXED WITH 25% H_2O, 3/4 IN. SURFACE COAT, LOW STRENGTH, NO PENETRATION OF SAND
VERY SMOOTH	UNK	UNK	UNK	UNK	UNK	LOW – SKILLED	MATERIAL IS HEAVY & WOULD REQUIRE HANDLING EQUIPMENT, MIXED WITH 25% H_2O, LOW STRENGTH, NO PENETRATION
SMOOTH	UNK	UNK	UNK	UNK	UNK	LOW – SKILLED	MIXED WITH 25% H_2O, 3/8 IN. SURFACE COAT, LOW STRENGTH, NO PENETRATION OF SAND
SMOOTH	UNK	UNK	UNK	UNK	UNK	LOW – SKILLED	MIXED WITH 25% H_2O, NO CURE OBTAINED
SMOOTH	UNK	UNK	UNK	UNK	UNK	LOW – SKILLED	MIXED WITH 20% H_2O, 1/2 IN. SURFACE COAT, BRITTLE, NO STRENGTH TEST, NO PENETRATION OF SAND
UNK	UNK	UNK	UNK	UNK	UNK	UNK	NO CURE AFTER 24 HRS
UNK	UNK	UNK	UNK	UNK	UNK	UNK	CURE TIME OVER 4 HRS
UNK	UNK	UNK	UNK	UNK	UNK	UNK	CURE TIME OVER 4 HRS
UNK	UNK	UNK	UNK	UNK	UNK	UNK	CURE TIME OVER 4 HRS
UNK	UNK	UNK	UNK	UNK	UNK	UNK	NO CURE
UNK	UNK	UNK	UNK	UNK	UNK	UNK	CURE TIME OVER 3 HRS
UNK	UNK	UNK	UNK	UNK	UNK	LOW SKILLED	LOW STRENGTH
UNK	UNK	UNK	UNK	UNK	UNK	UNK	CURE TIME OVER 4 HRS
UNK	UNK	UNK	UNK	UNK	UNK	UNK	1/4 IN. SURFACE COATING, RUBBERY AND SOFT, WILL NOT WITHSTAND LOADS, NO STRENGTH TEST
UNK	UNK	UNK	UNK	UNK	UNK	UNK	CURE TIME OVER 4 HRS
UNK	UNK	UNK	UNK	UNK	UNK	UNK	CURE TIME OVER 4 HRS
UNK	UNK	UNK	UNK	UNK	UNK	UNK	CURE TIME OVER 4 HRS
UNK	UNK	UNK	UNK	UNK	UNK	UNK	DID NOT BOND SAND TOGETHER, NO CURE
UNK	UNK	UNK	UNK	UNK	UNK	UNK	DID NOT BOND SAND TOGETHER, NO CURE
UNK	UNK	UNK	UNK	UNK	UNK	UNK	SAND COMPACTS INTO EASILY BROKEN 1/4 IN. LAYER, NO STRENGTH TEST
UNK	UNK	UNK	UNK	UNK	UNK	LOW SKILLED	LOW STRENGTH, SAMPLE BROKE DURING HANDLING, REQUIRES 10% ACID SOLUTION FOR CURING, DANGEROUS TO HANDLE, NO STRENGTH TEST

ED NOTE 4: TEMPERATURE TO BE ABOVE FREEZING POINT OF COMPOUND AND NOT EXCEEDING 90 F

RY NOTE 5: POT LIFE IS USEABLE TIME PERIOD FOR PREMIXED COMPONENTS PRIOR TO APPLICATION.

OF NOTE 6: WATER REQUIRED FOR MIXING MAY NOT BE AVAILABLE AT HELICOPTER PAD SITE NECESSITATING TRANSPORTATION OF WATER.

LEGEND:

UNACCOMPLISHED

UNK: UNKNOWN

Fig. A-4 Material Characteristics (Miscellaneous)

C

APPENDIX B

STRENGTH AND CURE TIME CHARACTERISTICS

The following figures (B-1 through B-30) show the test results for those specimens subjected to structural testing during the small-scale test program as described in Par. 2.4.2. In addition, gel time characteristics are shown for each specimen tested.

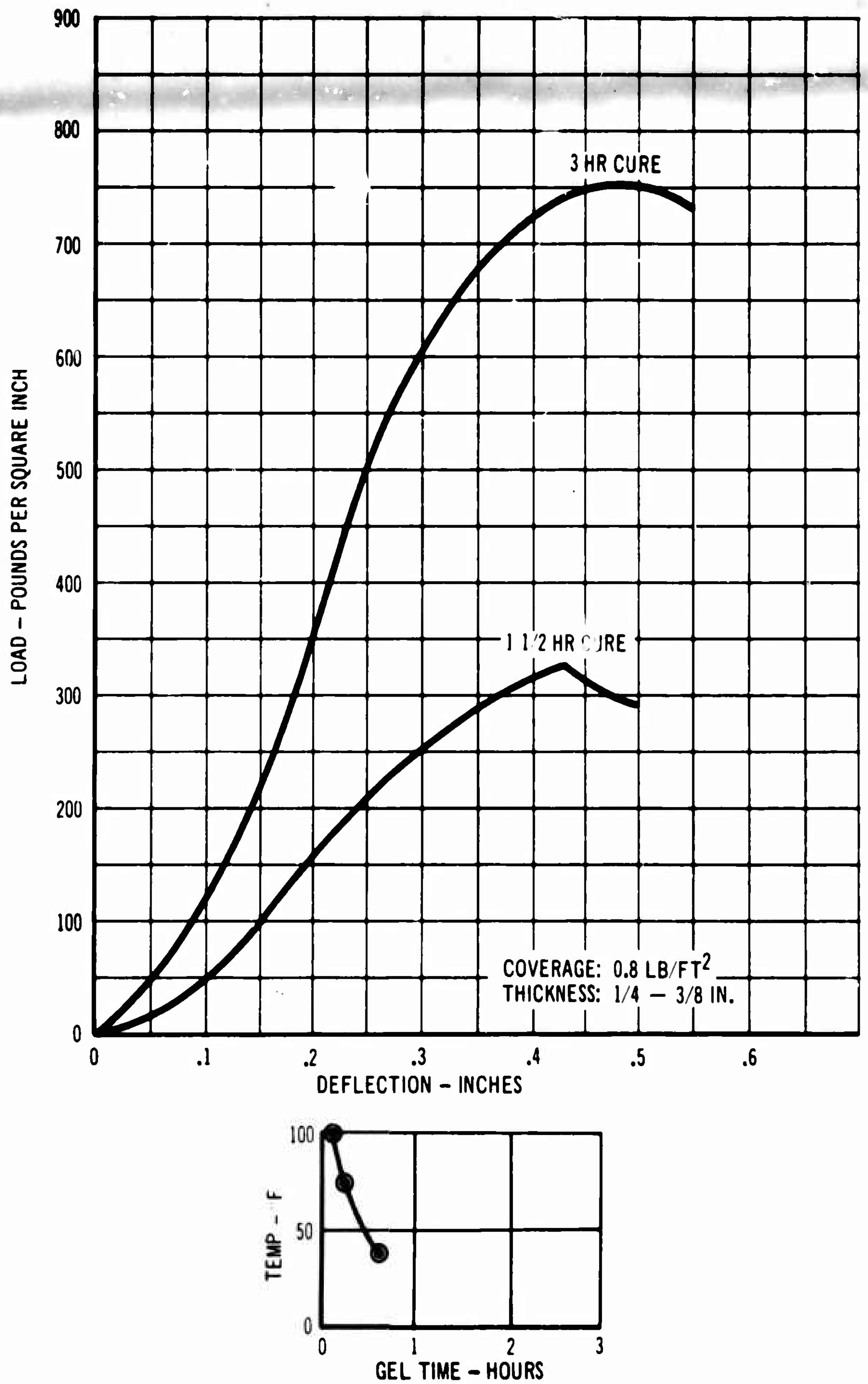


Fig. B-1 Structural and Gel Time Characteristics (Specimen No. 1)

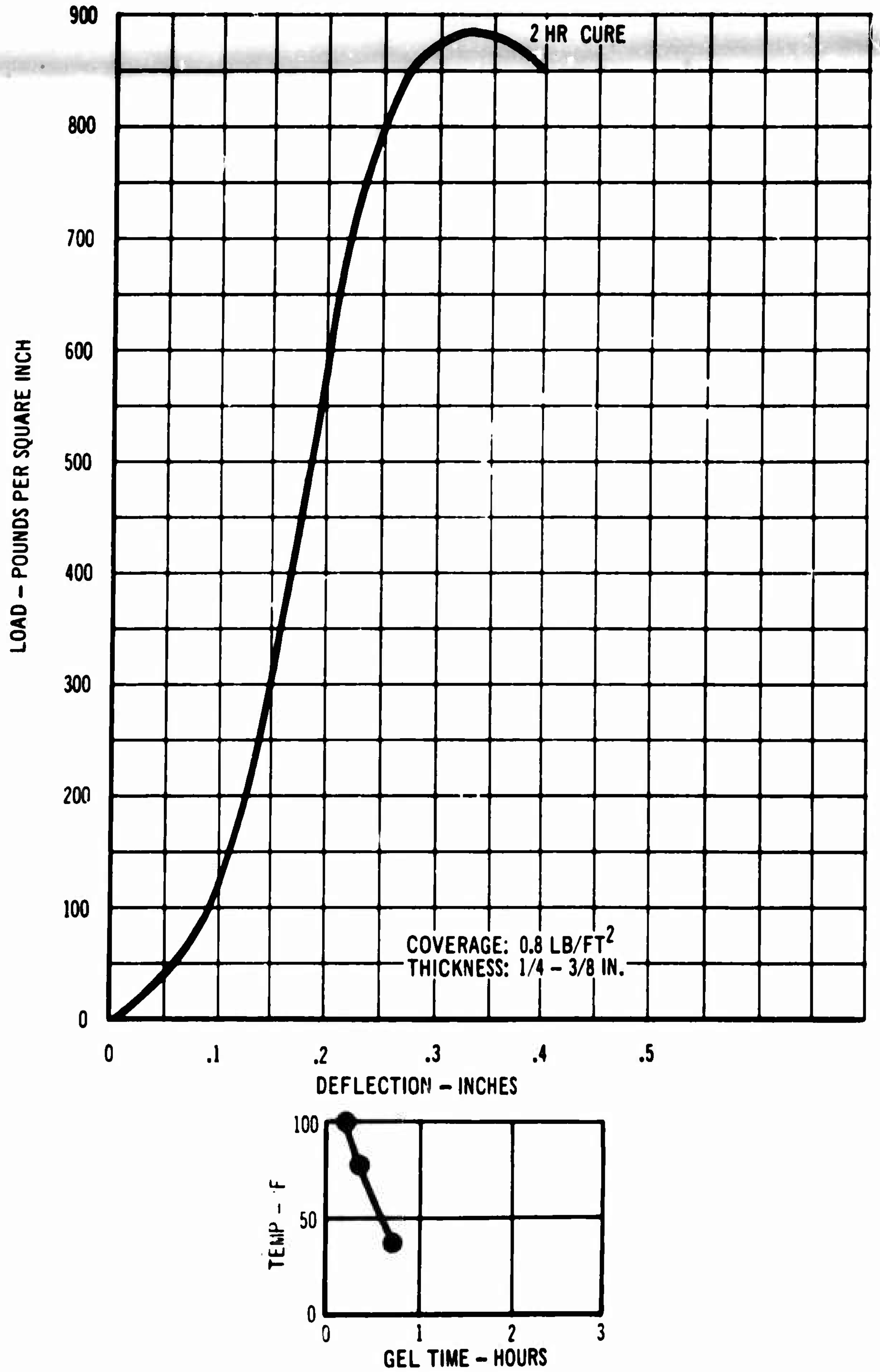
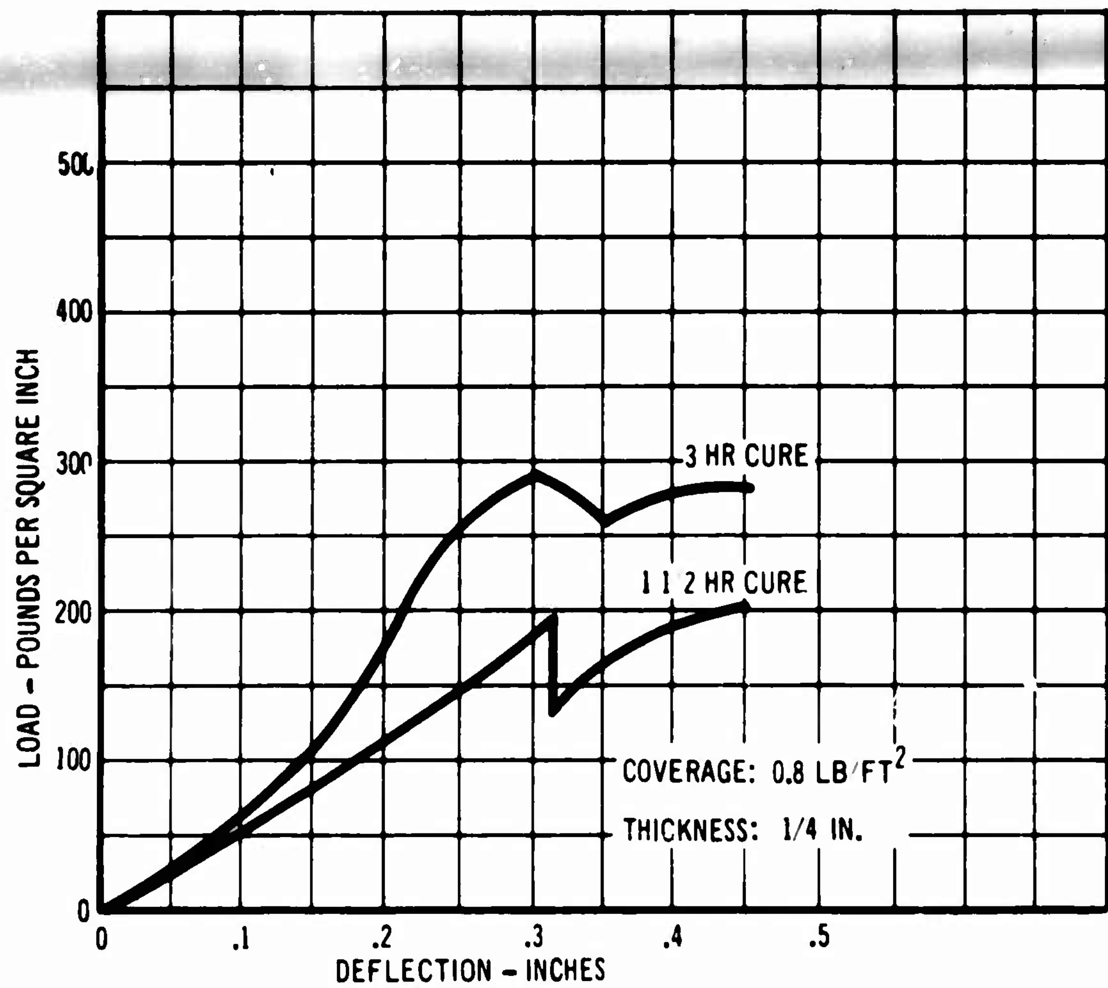


Fig. B-2 Structural and Gel Time Characteristics (Specimen No. 2)



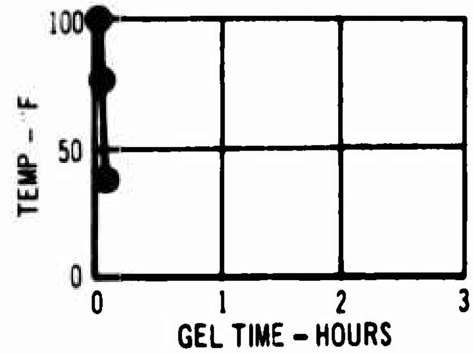
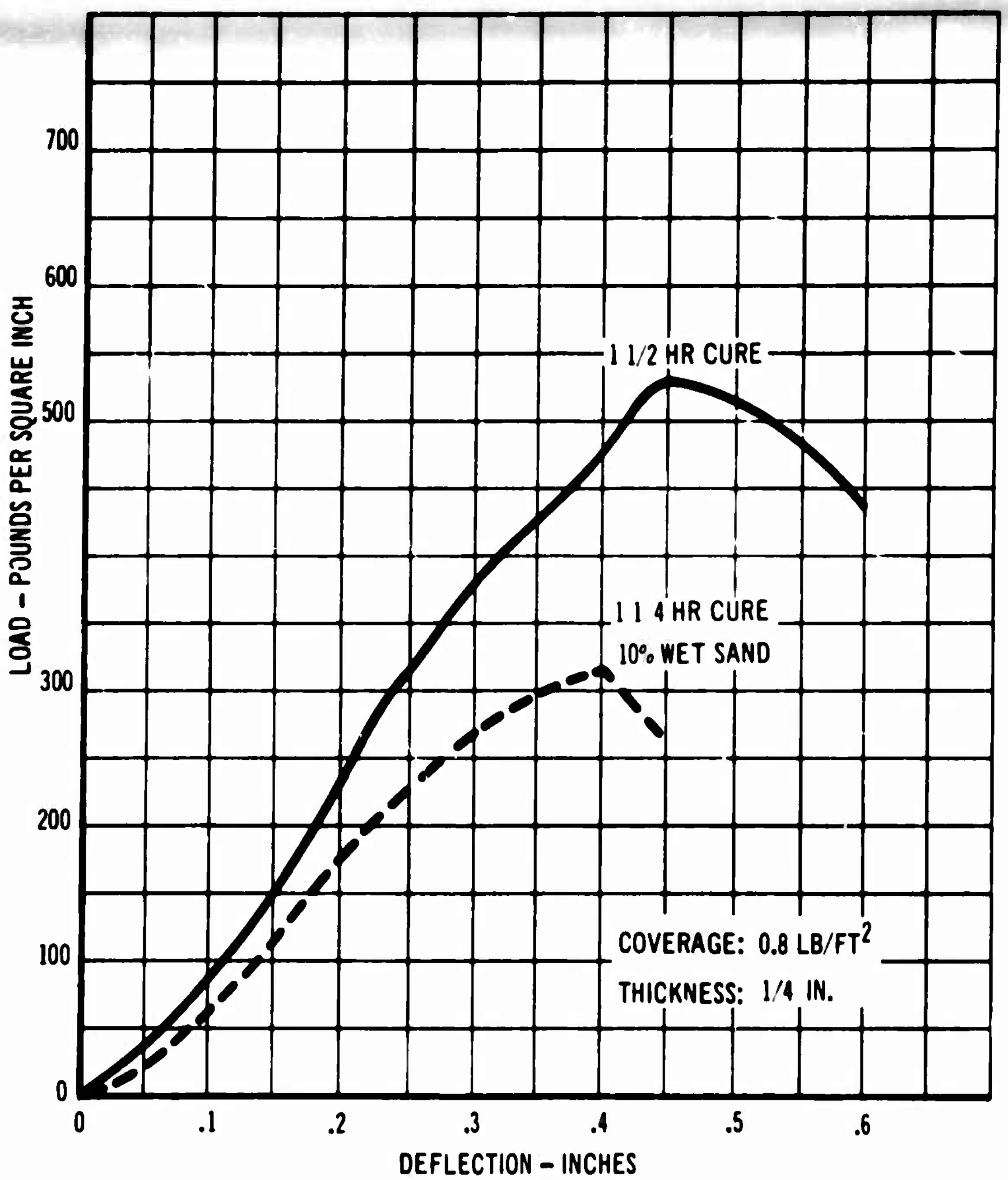


Fig. B-3 Structural and Gel Time Characteristics (Specimen No. 3)



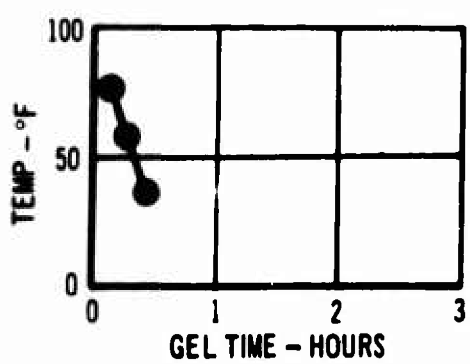


Fig. B-4 Structural and Gel Time Characteristics (Specimen No. 4)

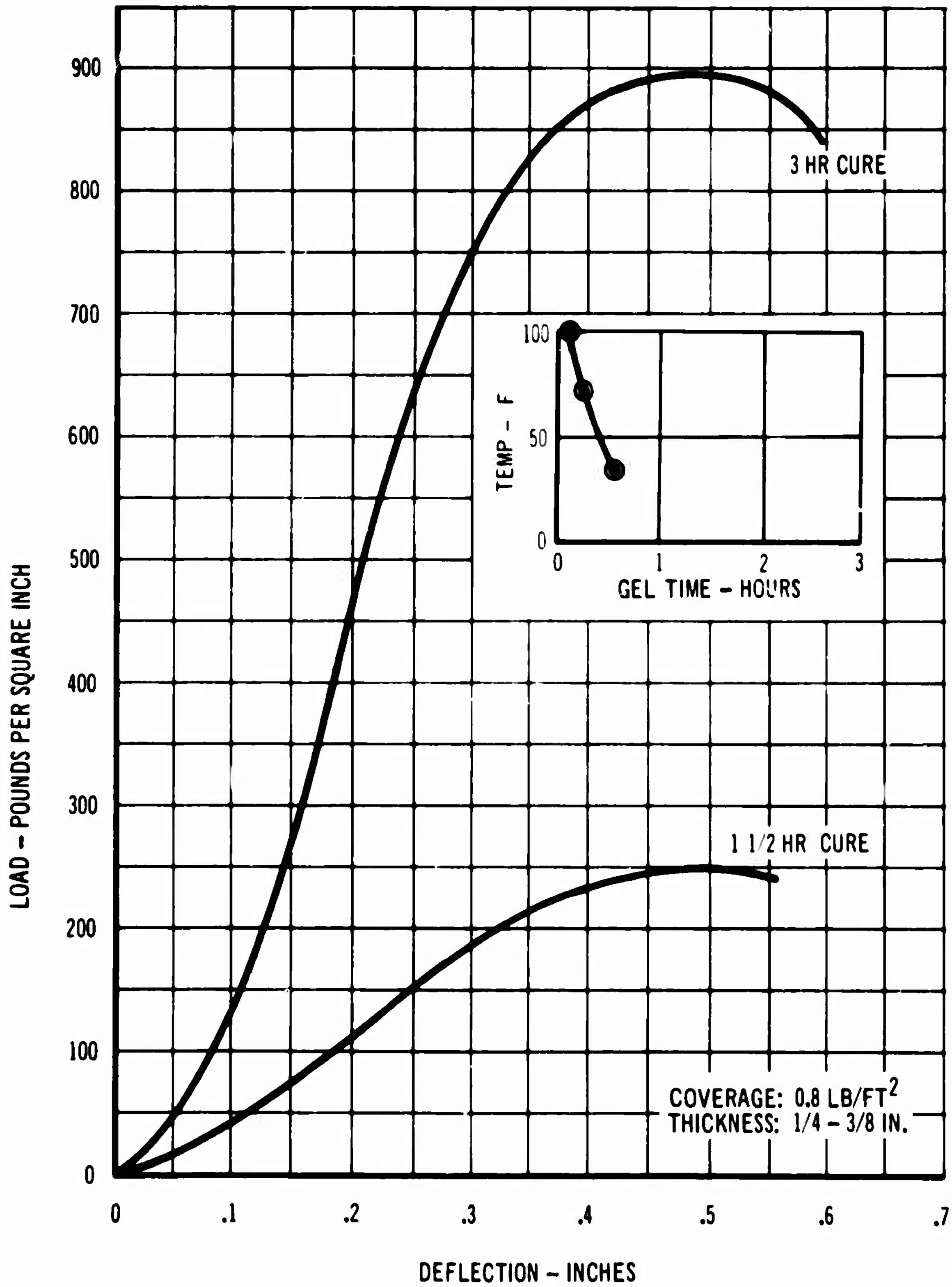
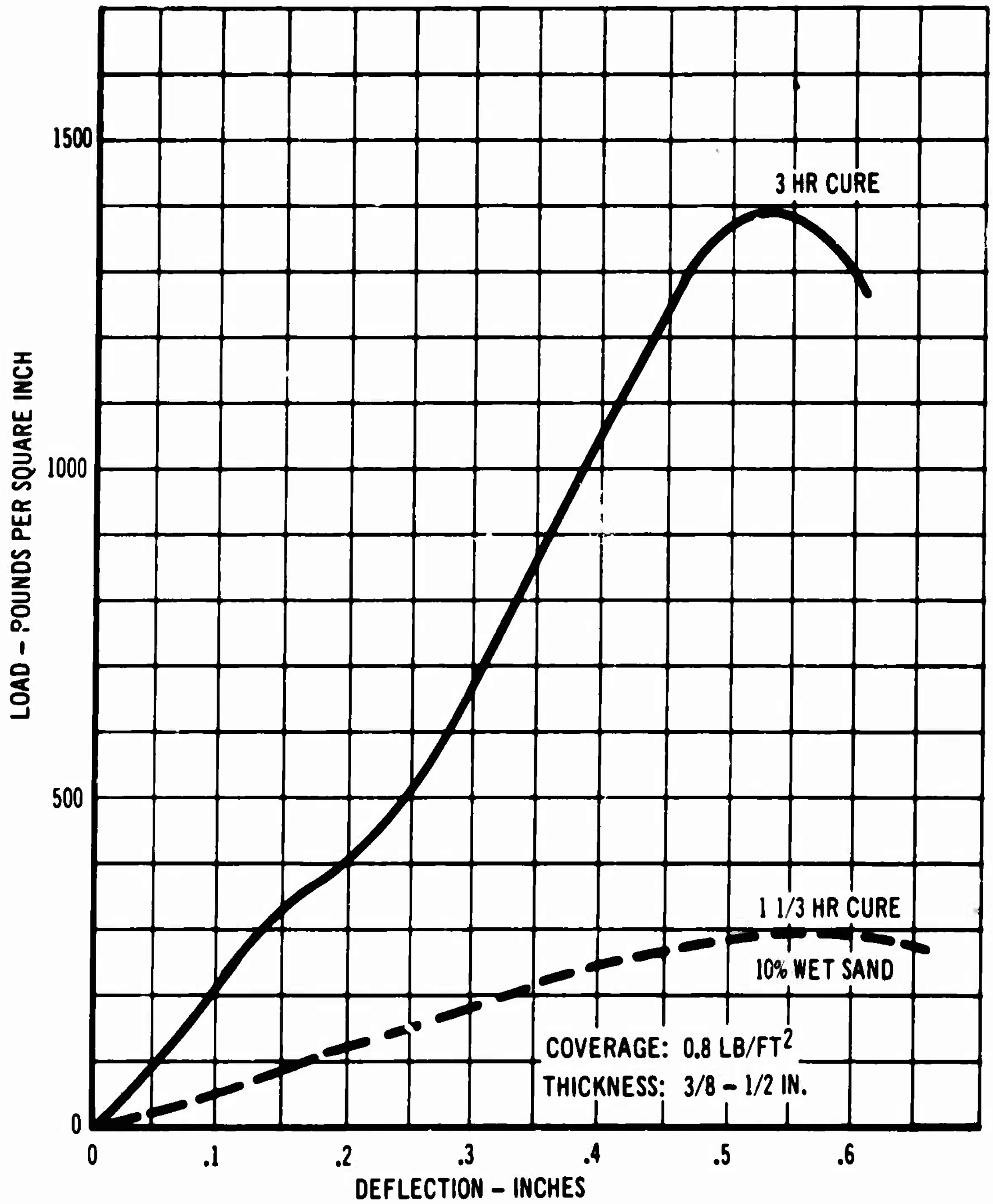


Fig. B-5 Structural and Gel Time Characteristics (Specimen No. 5)



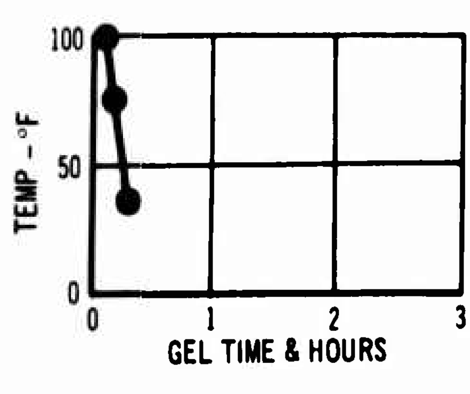
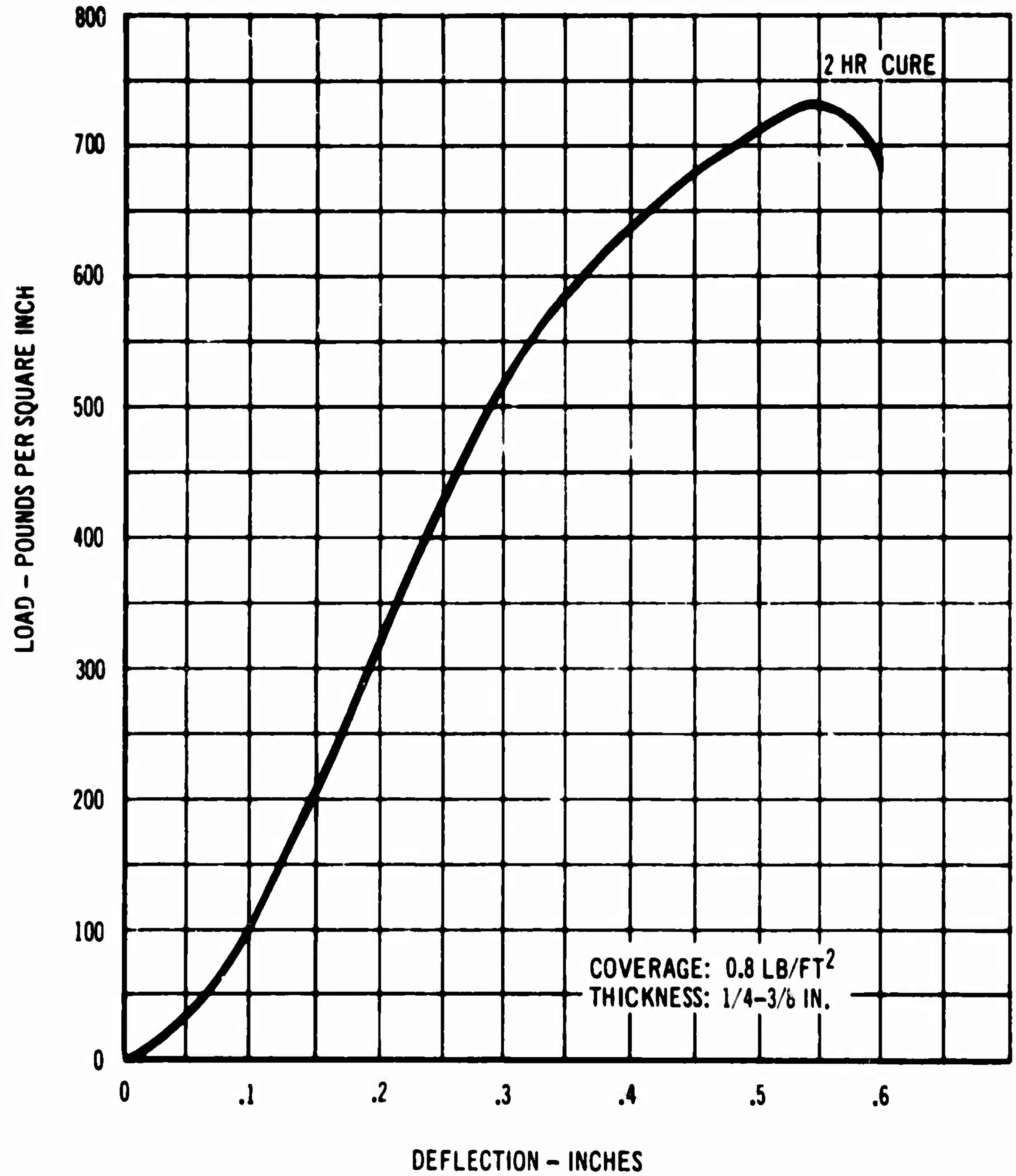


Fig. B-6 Structural and Gel Time Characteristics (Specimen No. 6)



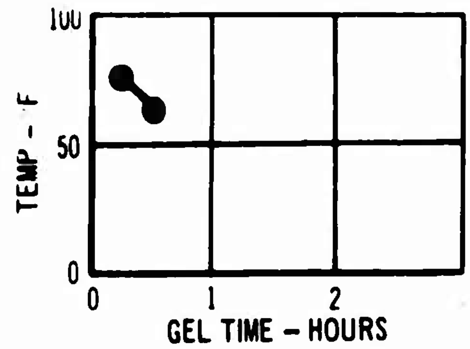


Fig. B-7 Structural and Gel Time Characteristics (Specimen No. 9)

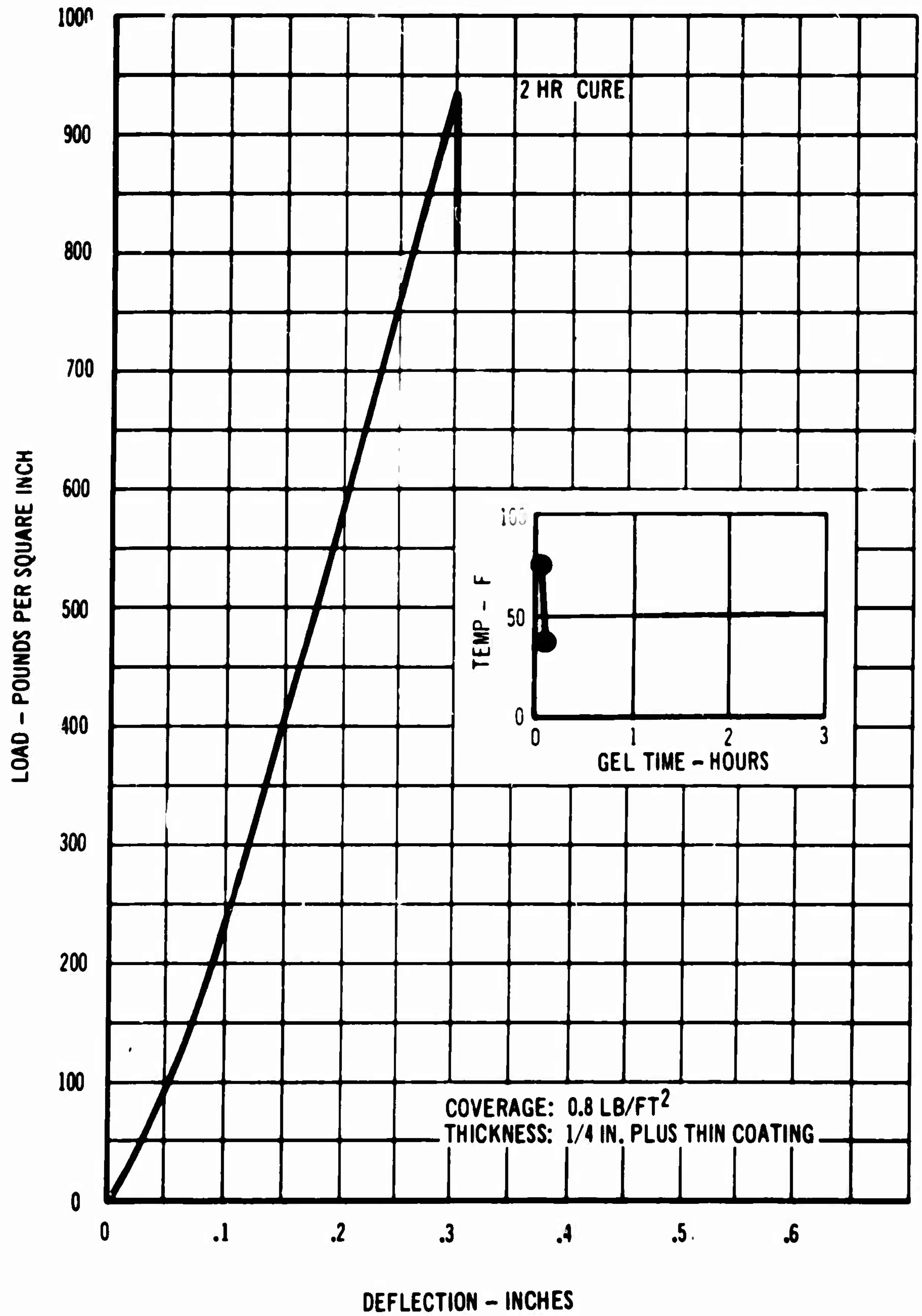


Fig. B-8 Structural and Gel Time Characteristics (Specimen No. 10)

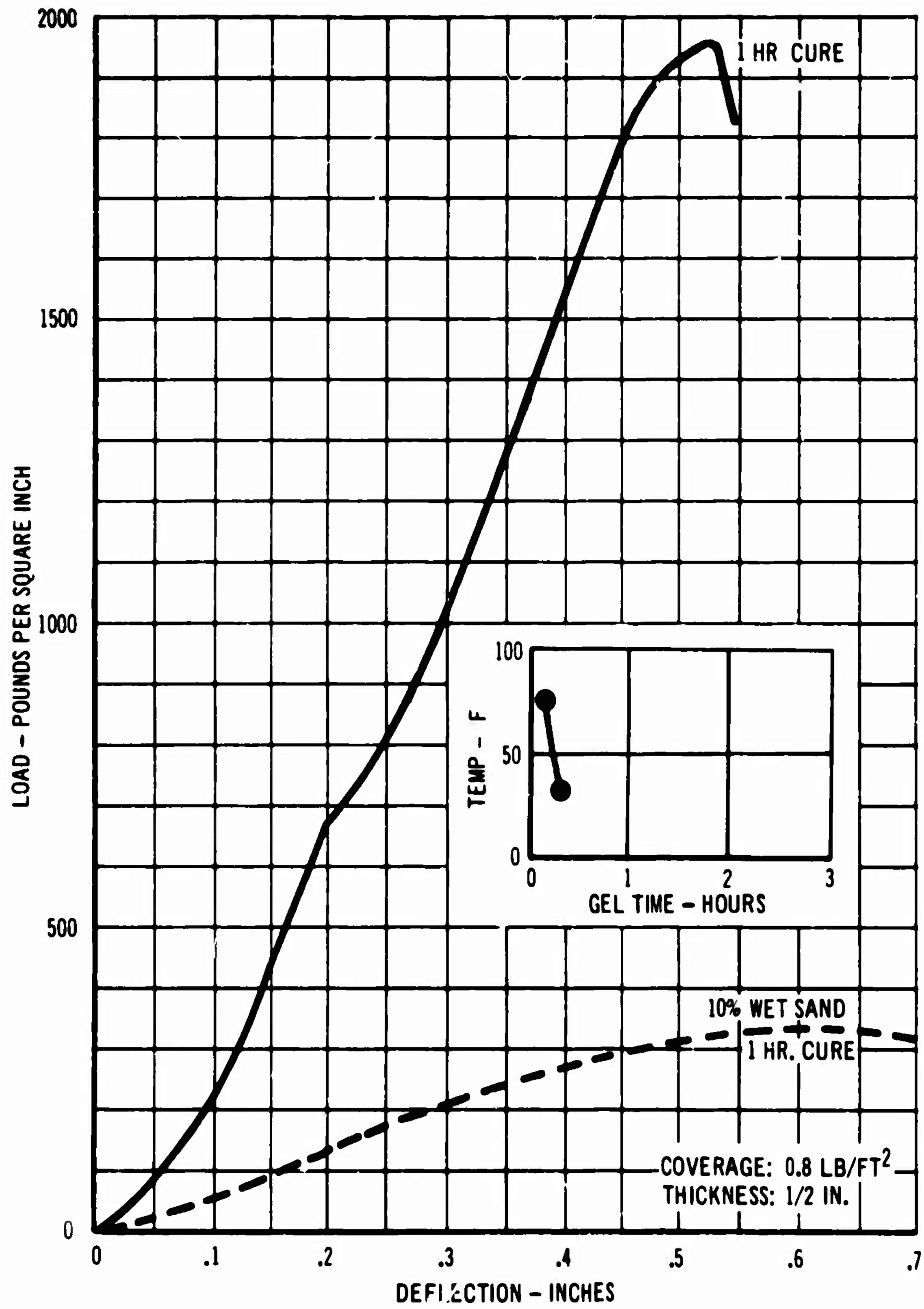


Fig. B-9 Structural and Gel Time Characteristics (Specimen No. 11)

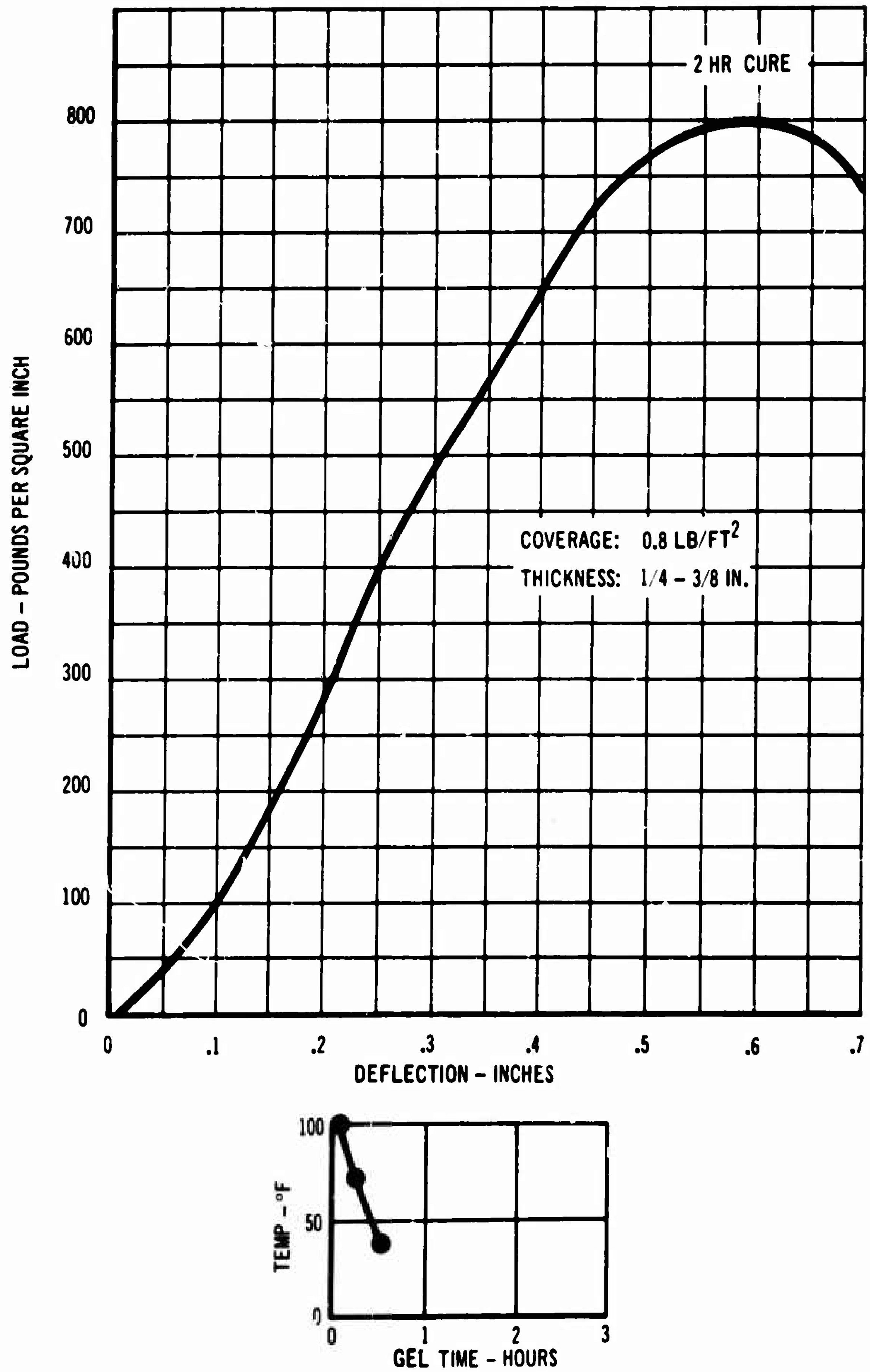
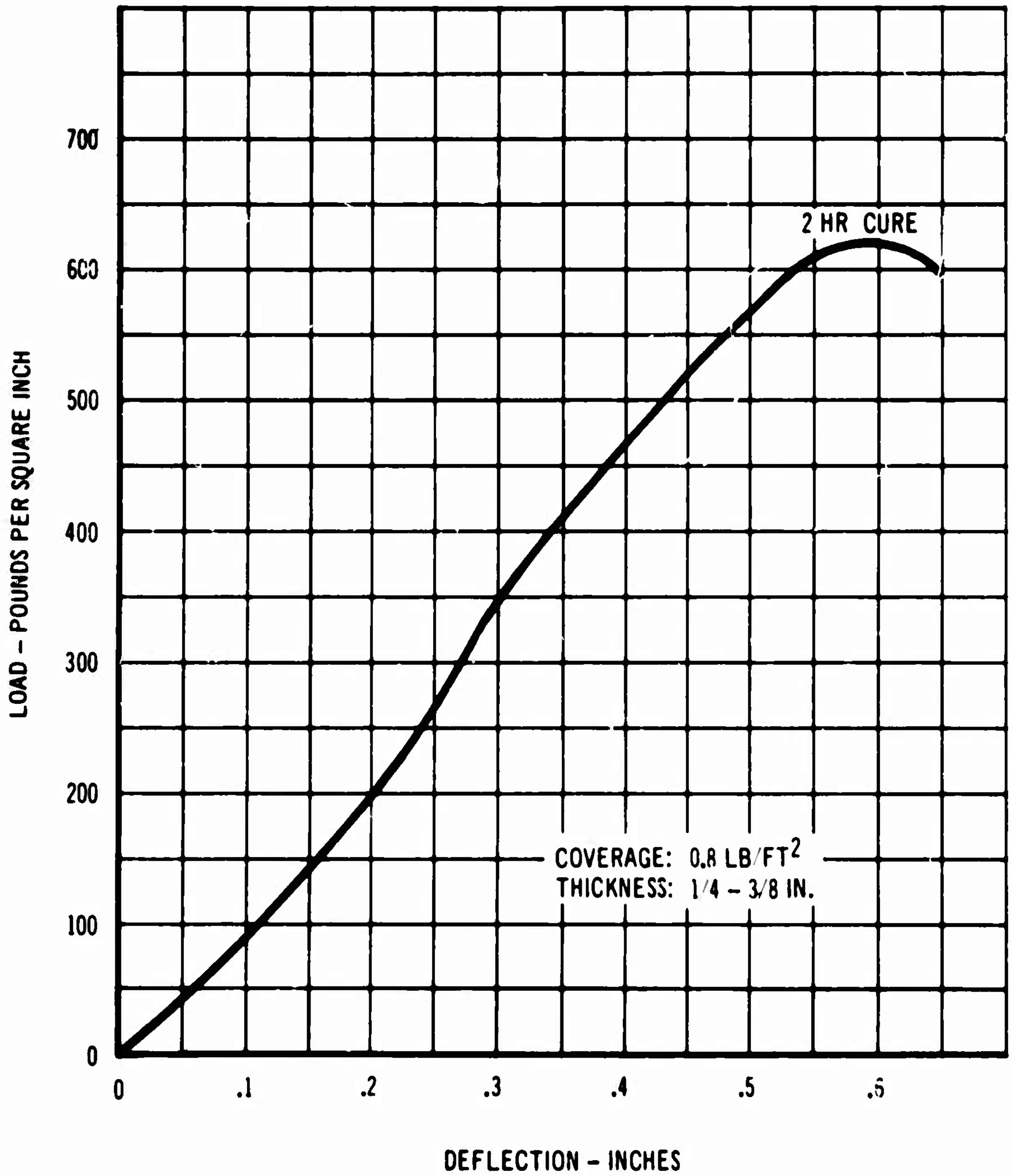


Fig. B-10. Structural and Gel Time Characteristics (Specimen No. 12)



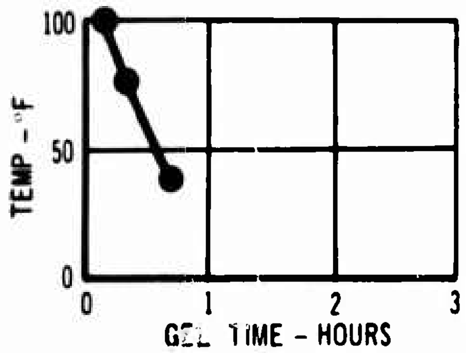


Fig. B-11 Structural and Gel Time Characteristics (Specimen No. 13)

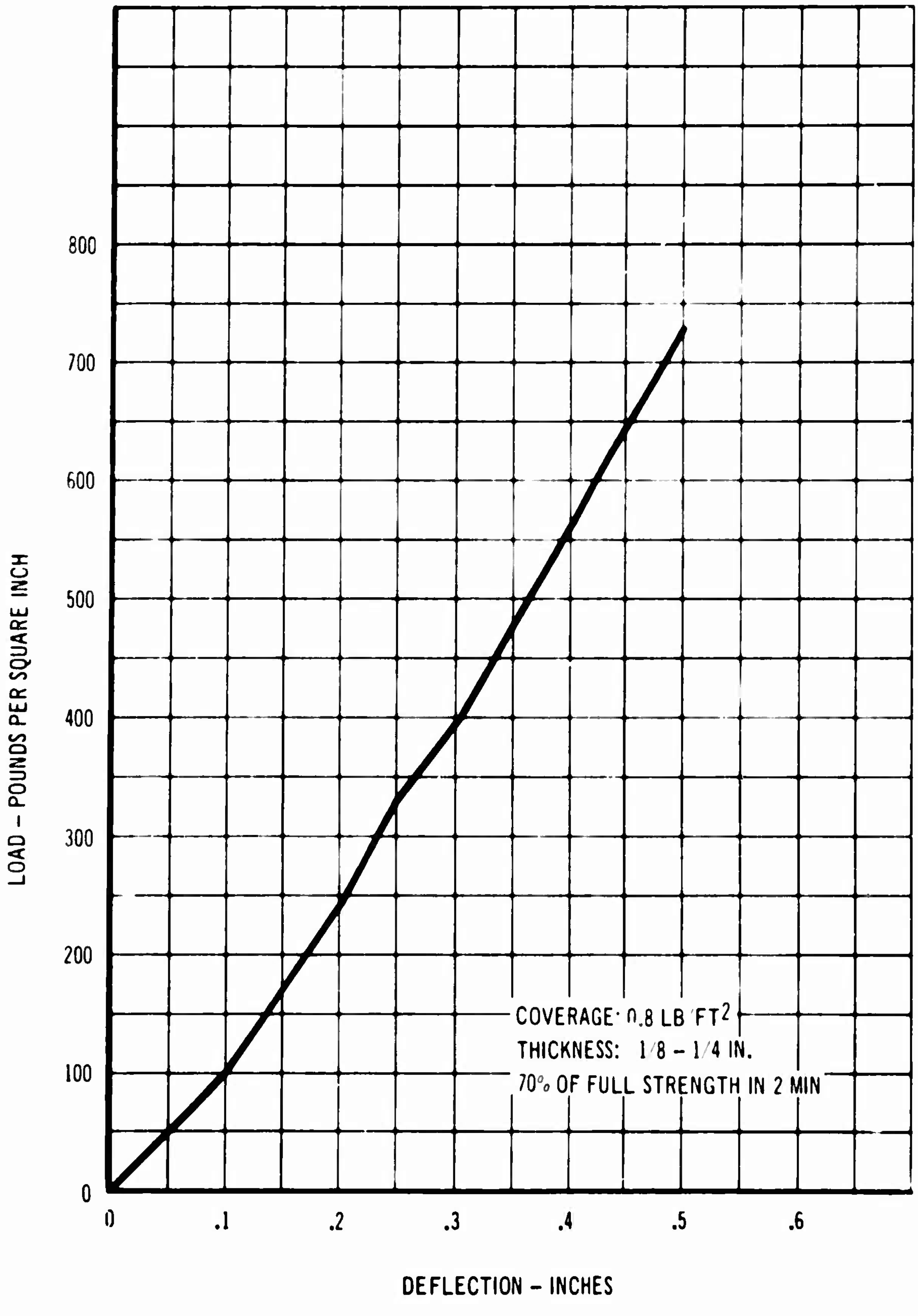


Fig. B-12 Structural and Gel Time Characteristics (Specimen No. 14)

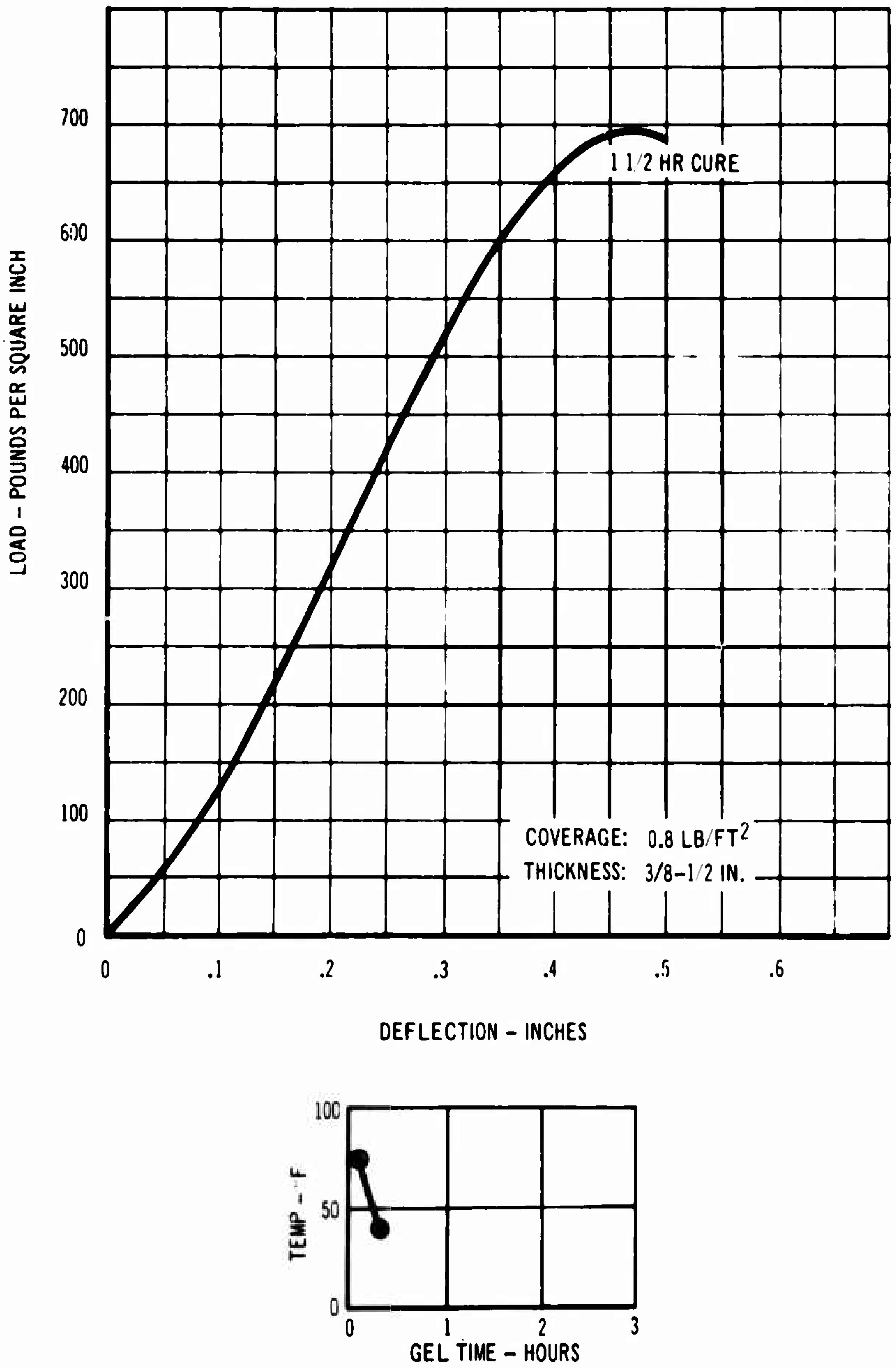
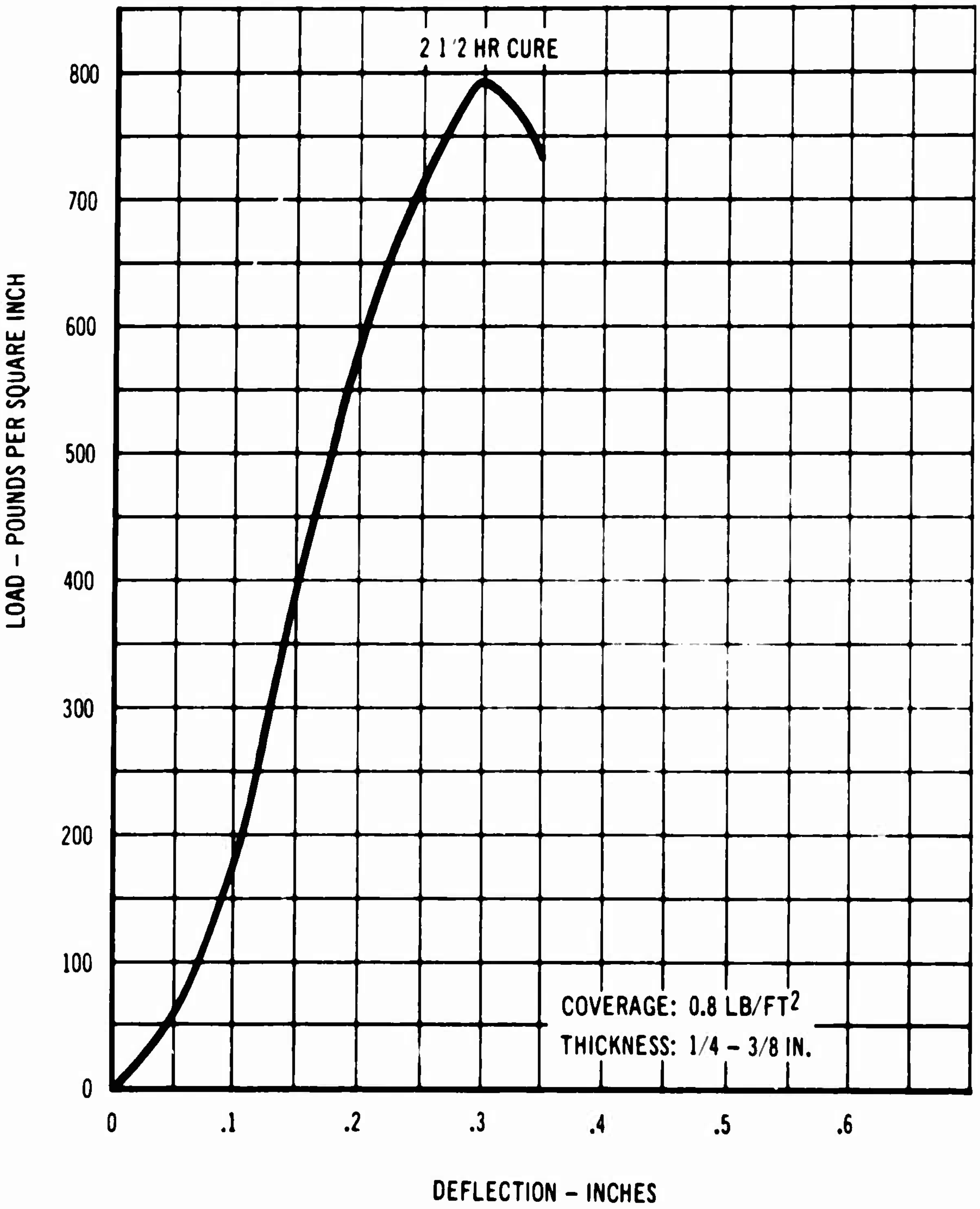


Fig. B-13 Structural and Gel Time Characteristics (Specimen No. 16)



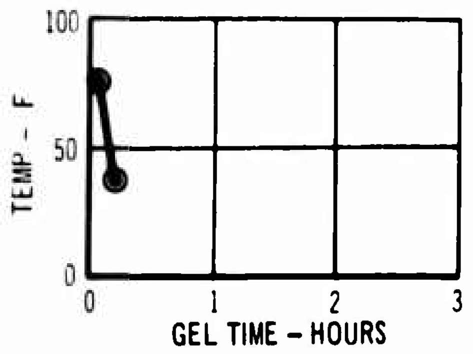
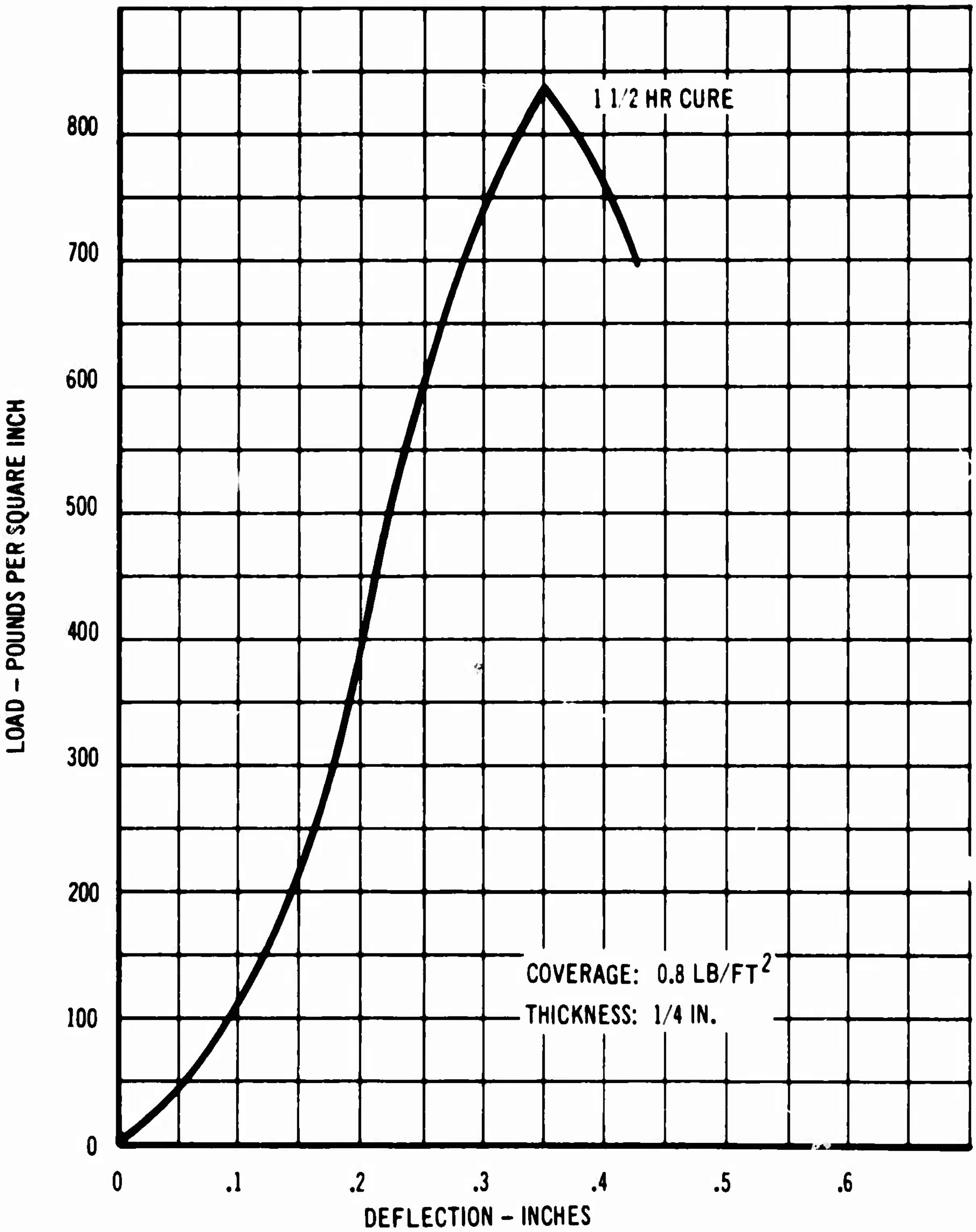


Fig. B-14 Structural and Gel Time Characteristics (Specimen No. 17)



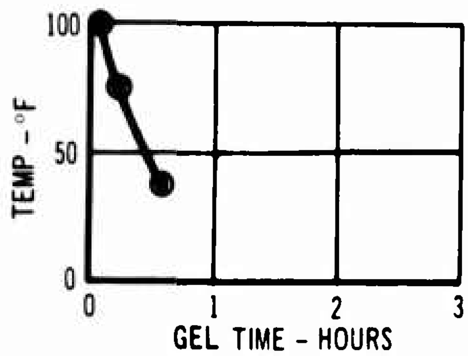


Fig. B-15 Structural and Gel Time Characteristics (Specimen No. 18)

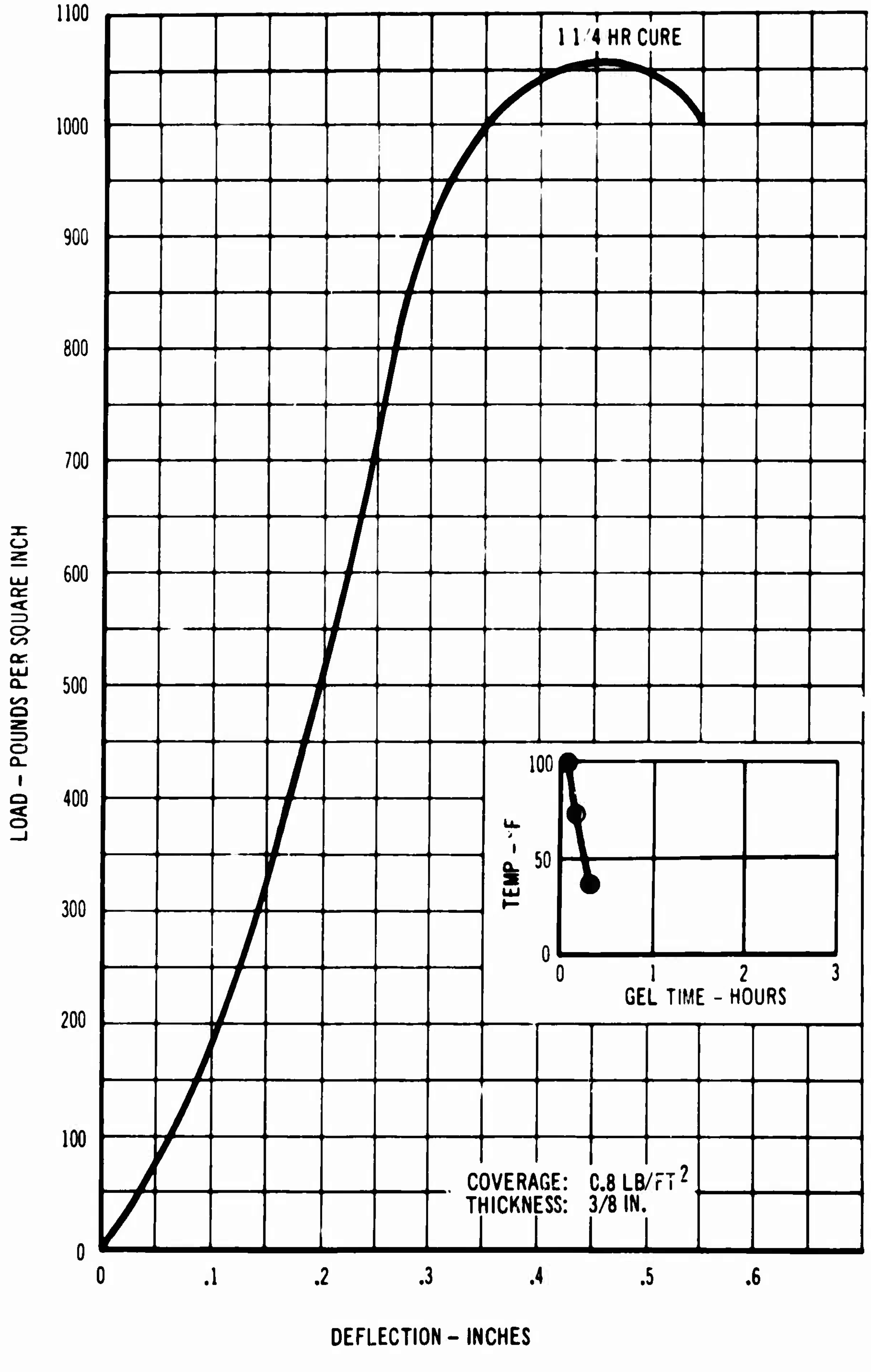
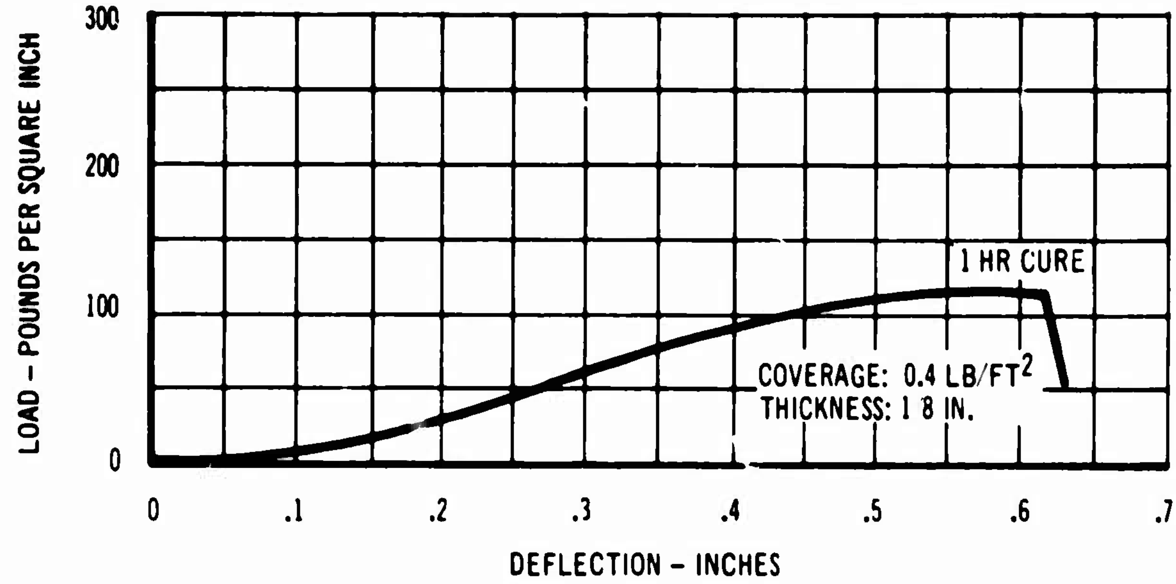


Fig. B-16 Structural and Gel Time Characteristics (Specimen No. 19)



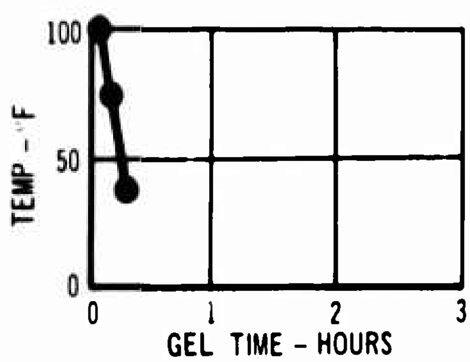


Fig. B-17 Structural and Gel Time Characteristics (Specimen No. 23)

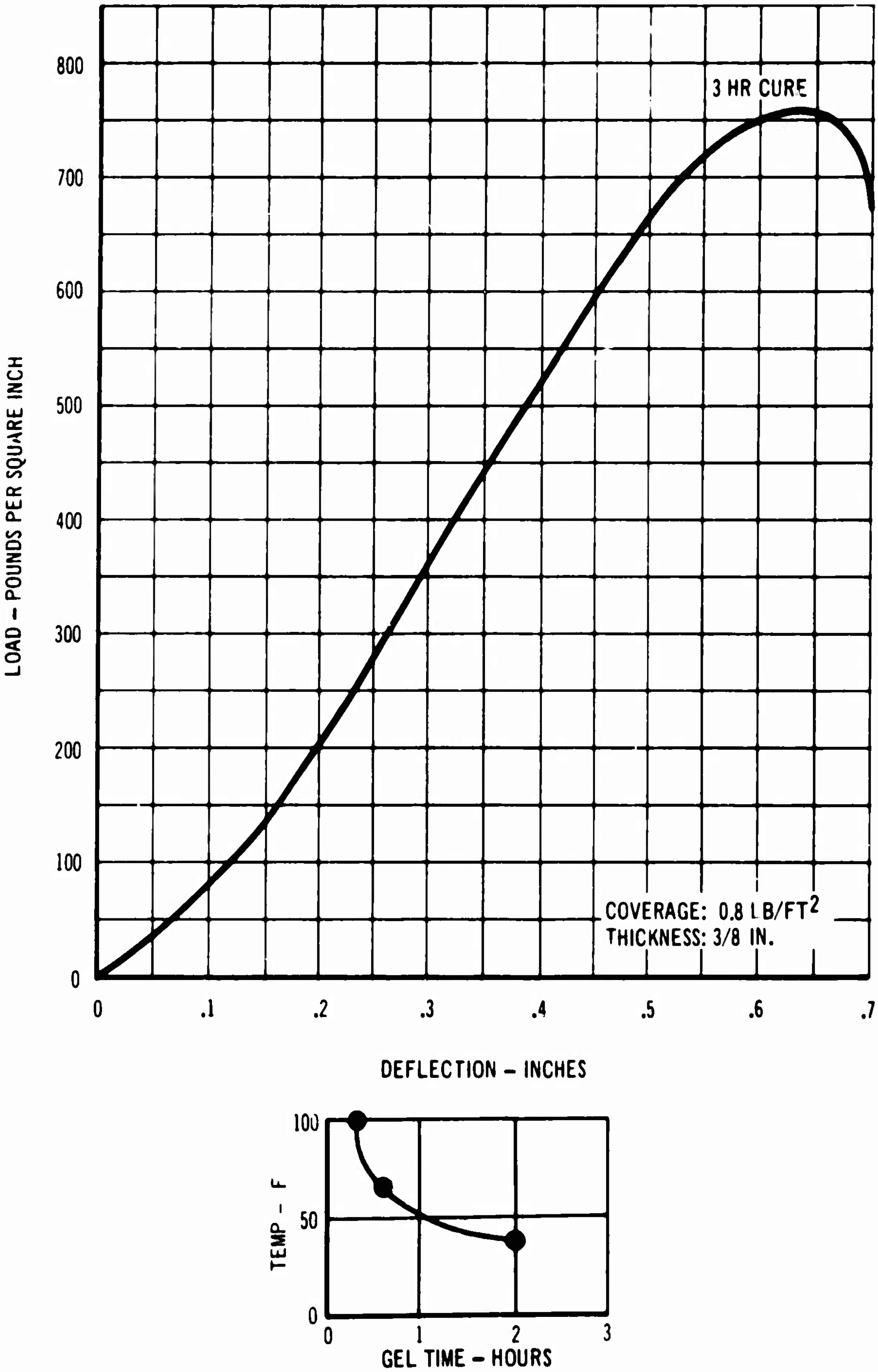
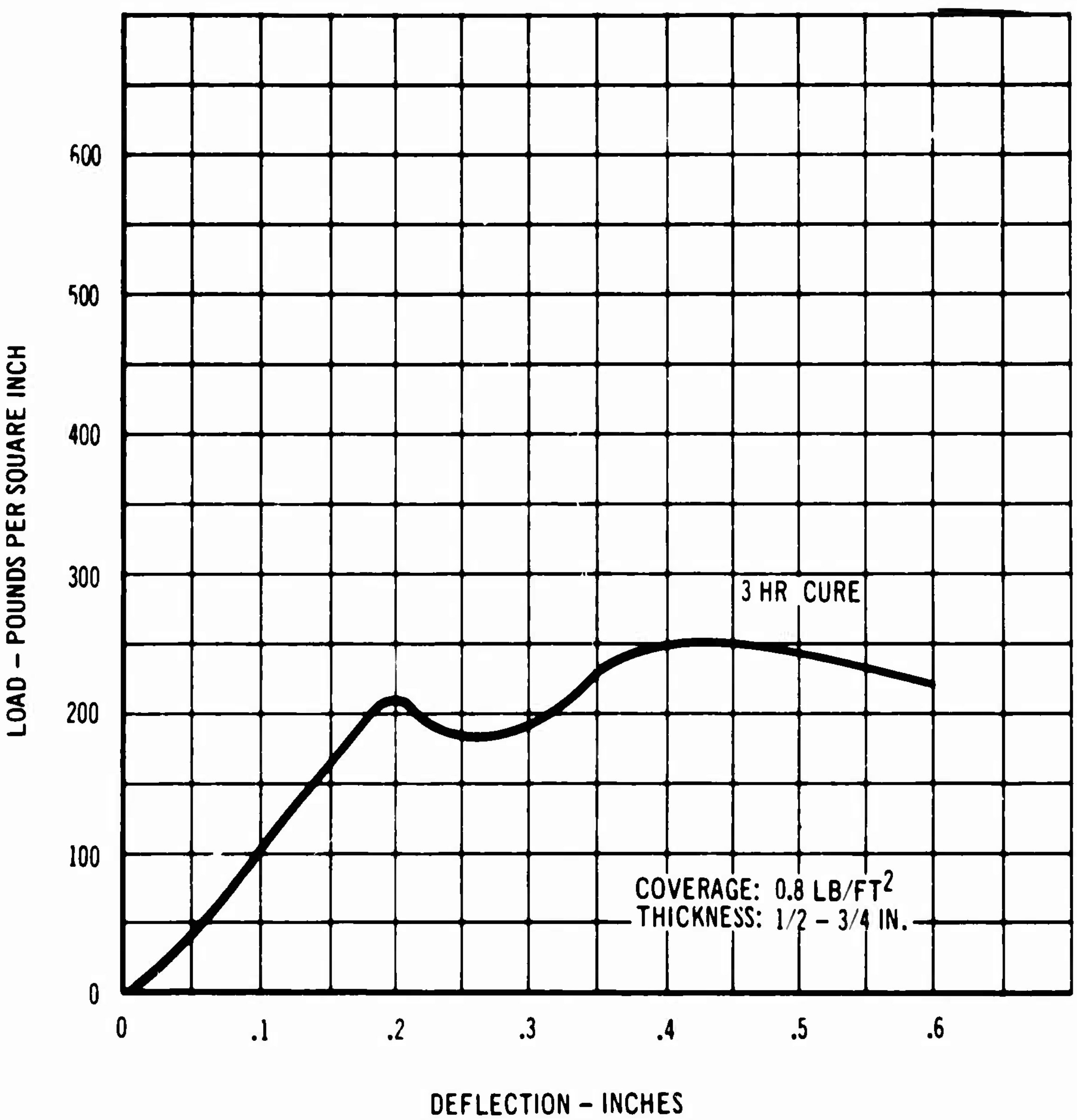


Fig. B - 18 Structural and Gel Time Characteristics (Specimen No. 28)



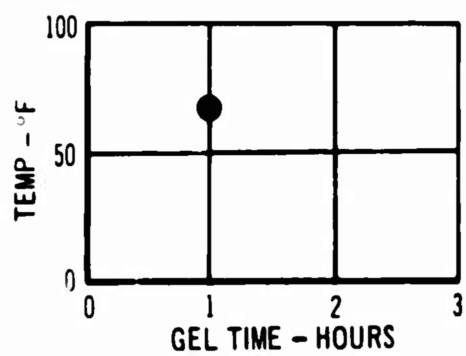


Fig. B-19 Structural and Gel Time Characteristics (Specimen No. 29)

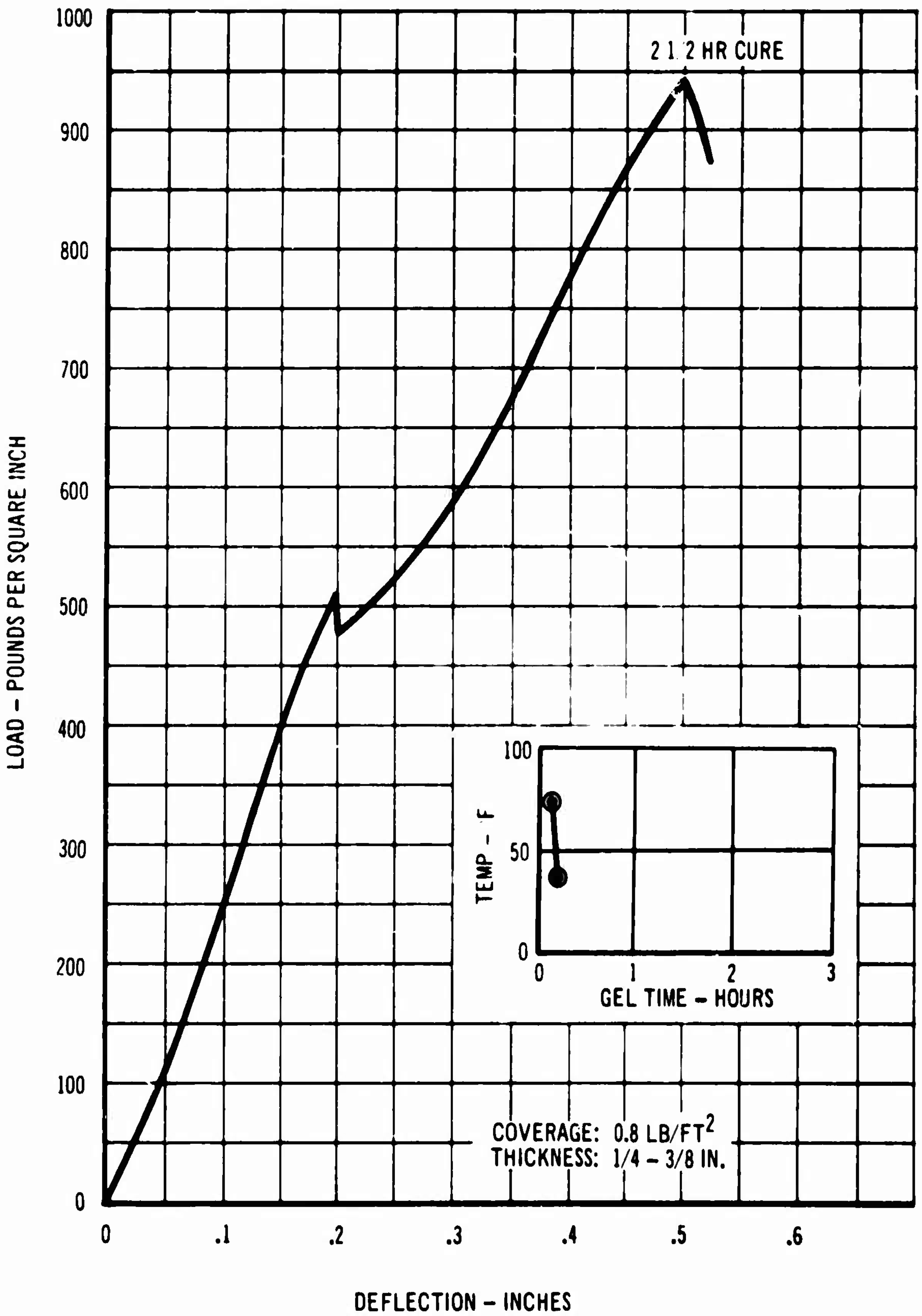


Fig. B-20 Structural and Gel Time Characteristics (Specimen No. 32)

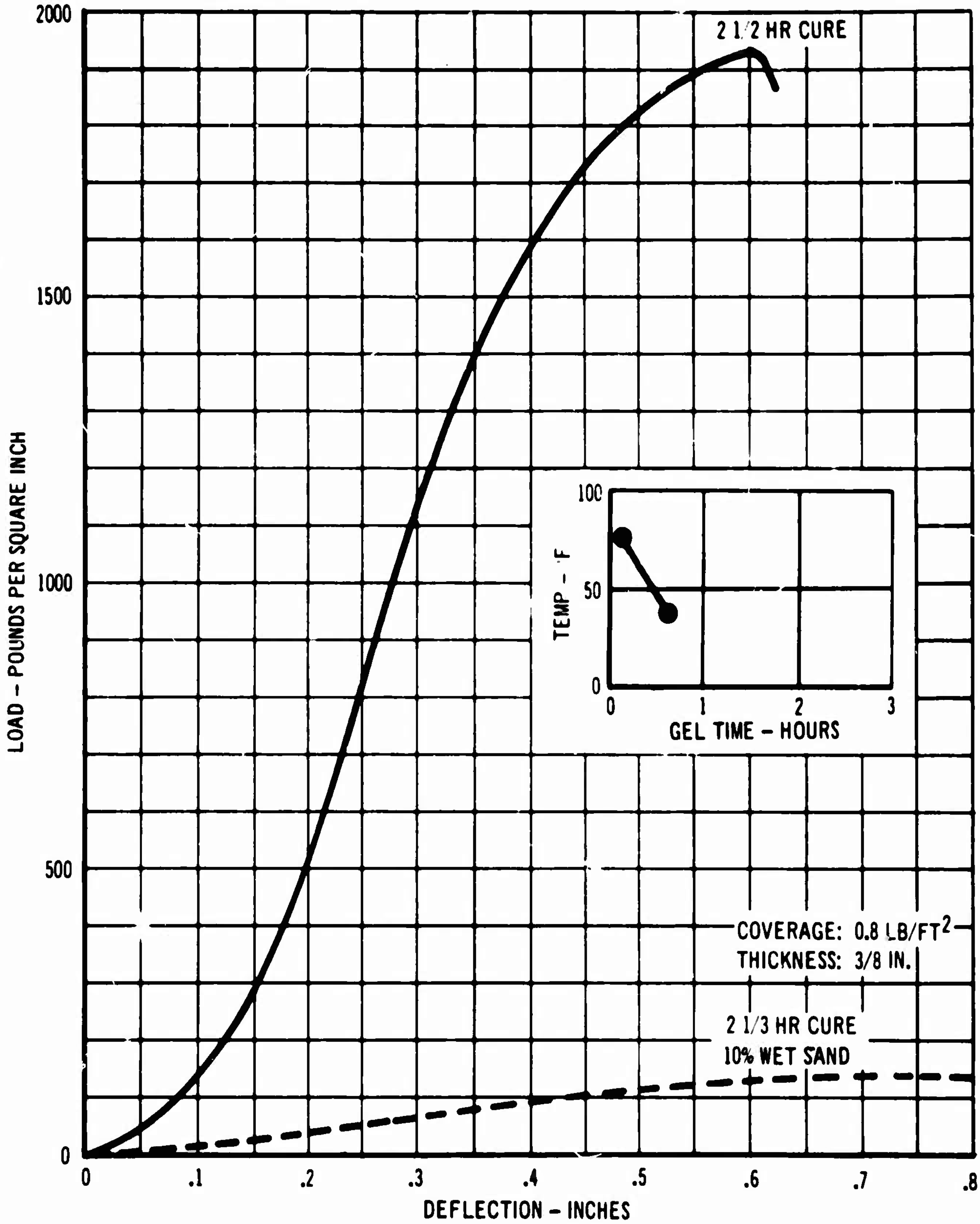


Fig. B-21 Structural and Gel Time Characteristics (Specimen No. 33)

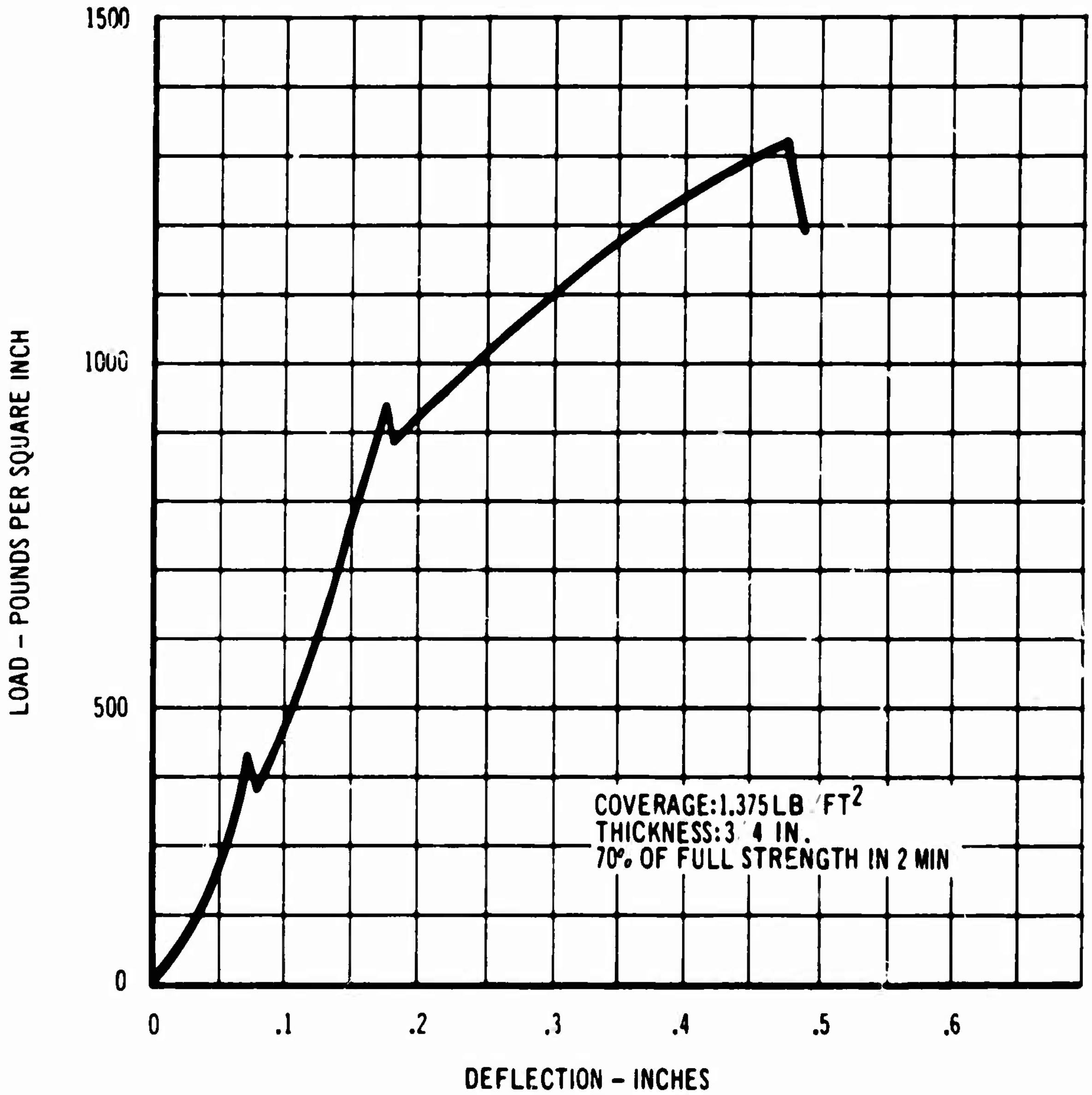


Fig. B-22 Structural and Gel Time Characteristics (Specimen No. 41)

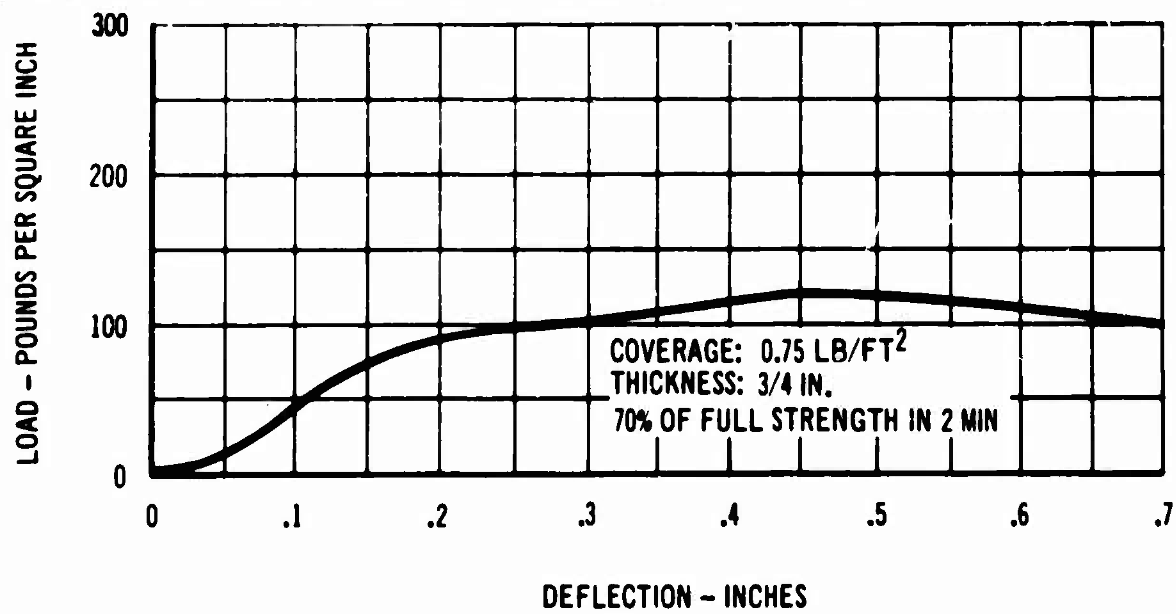


Fig. B-23 Structural and Gel Time Characteristics (Specimen No. 46)

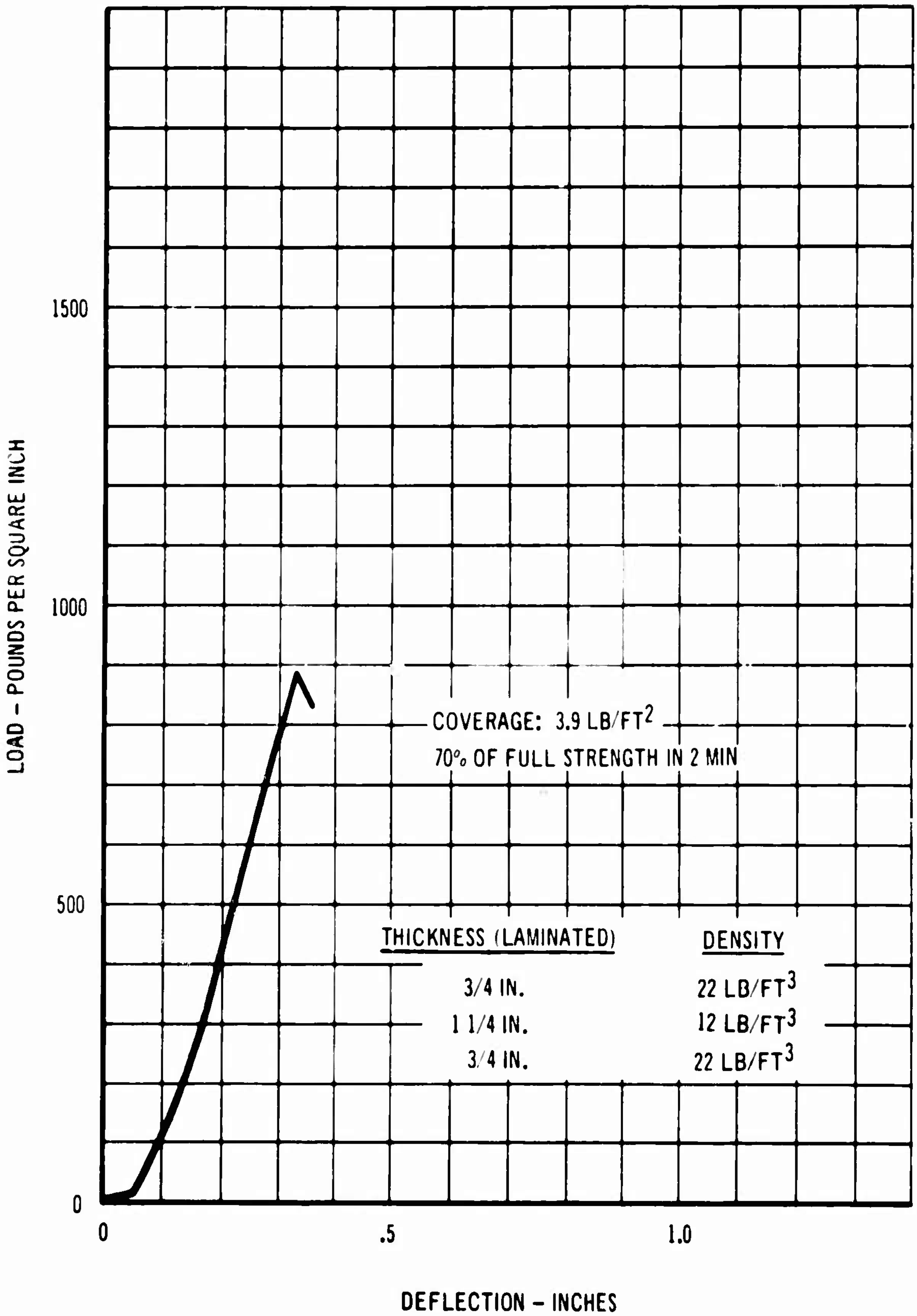


Fig. B-24 Structural and Gel Time Characteristics (Specimen No. 47)

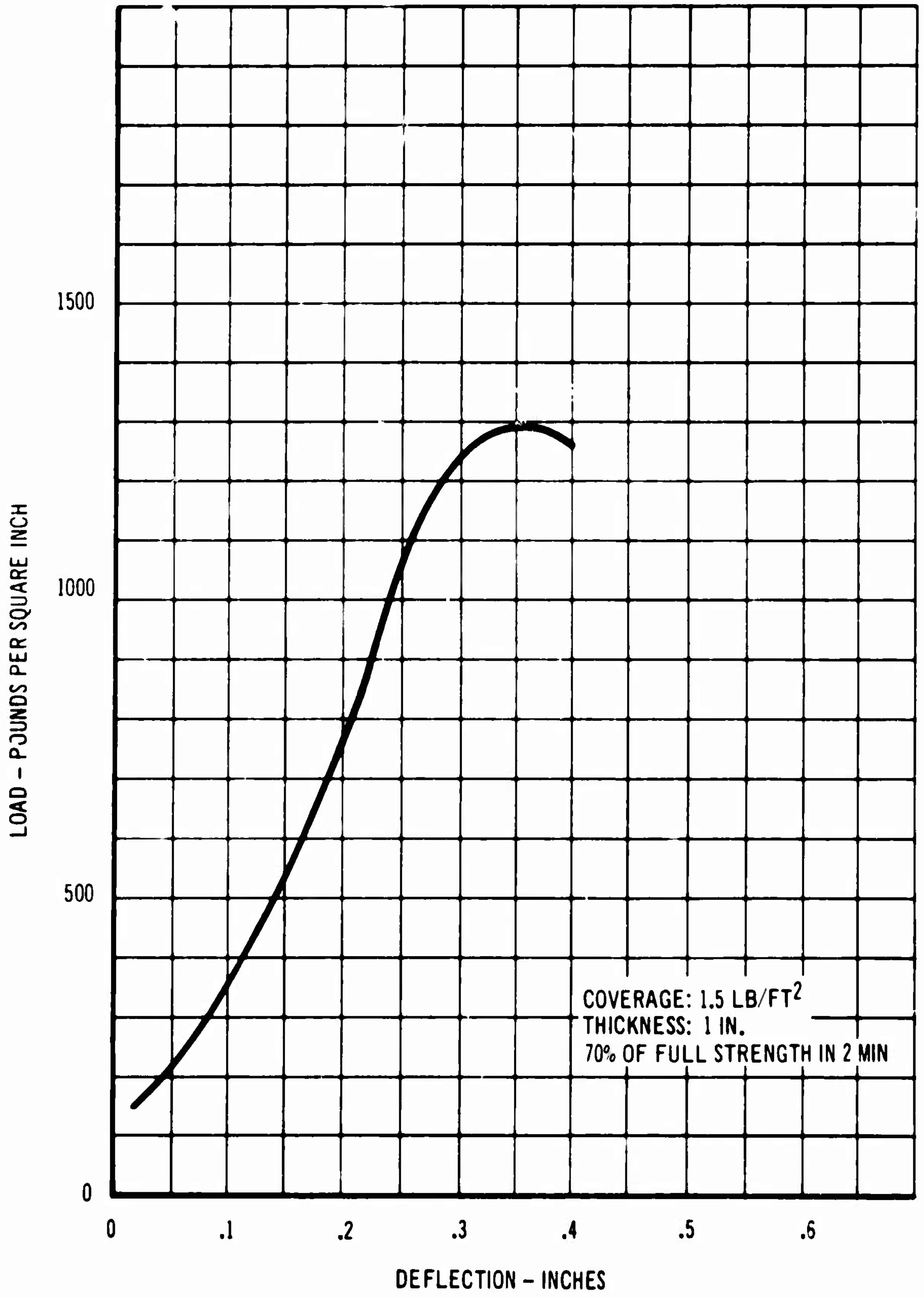


Fig. B-25 Structural and Gel Time Characteristics (Specimen No. 49)

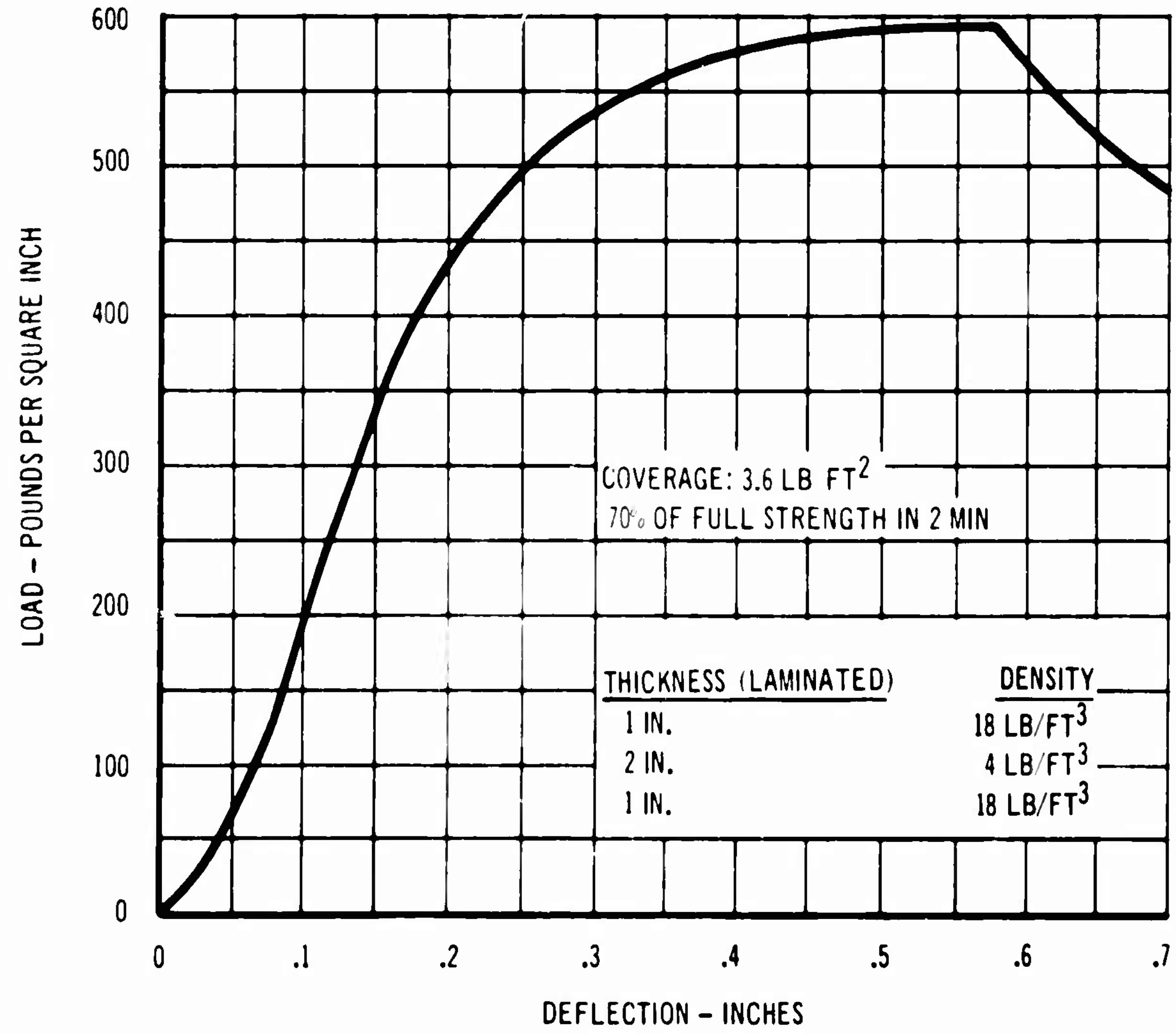


Fig. B-26 Structural and Gel Time Characteristics (Specimen No. 50)

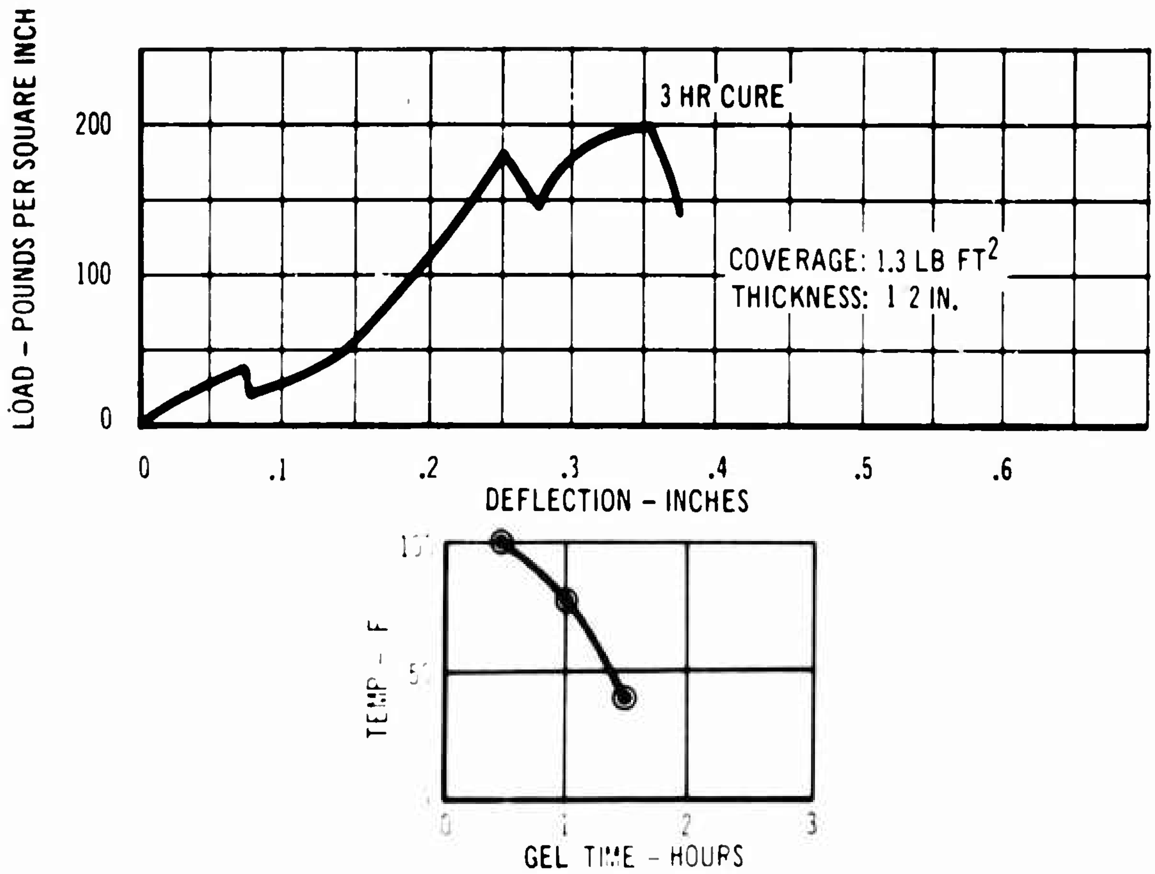


Fig. B-27 Structural and Gel Time Characteristics (Specimen No. 52)

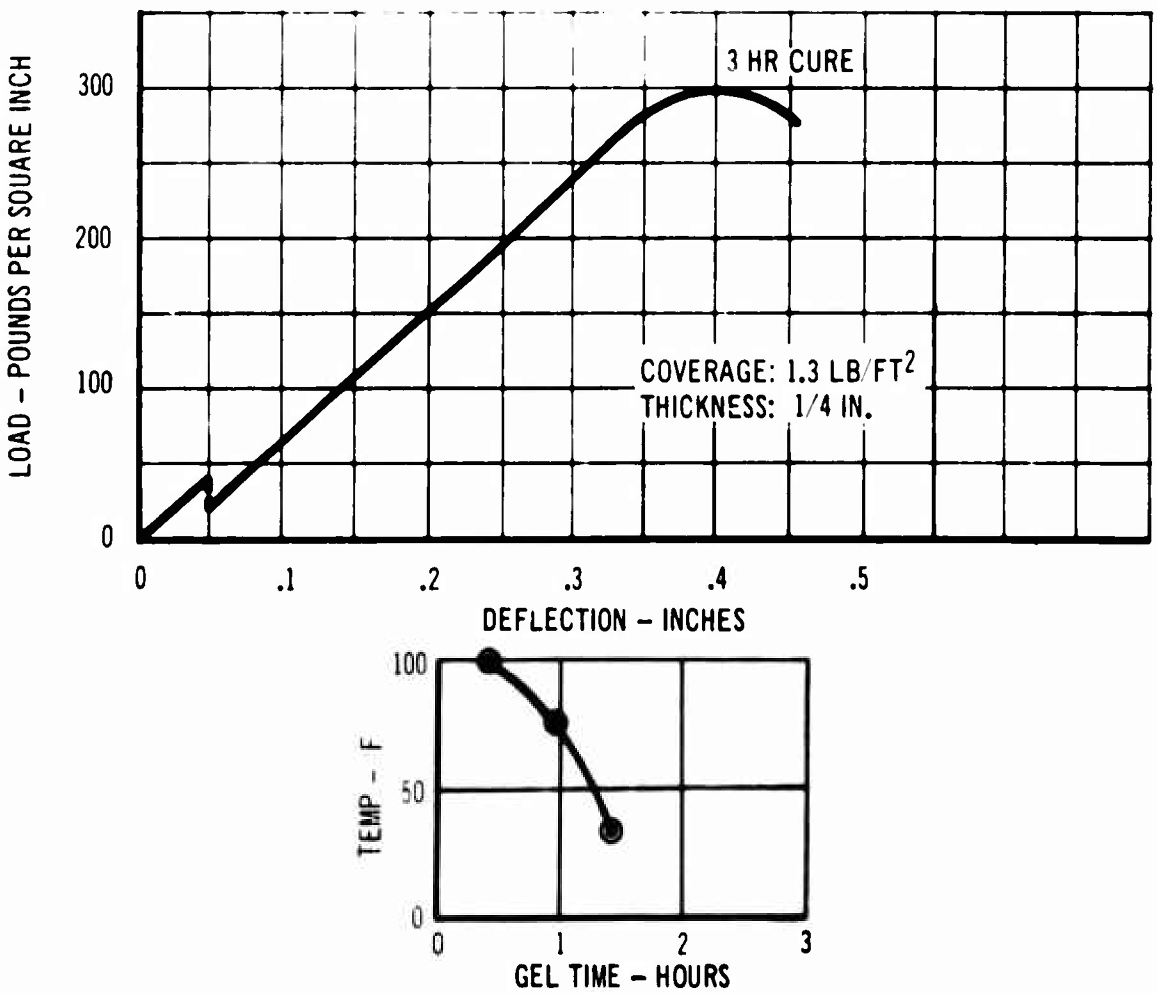
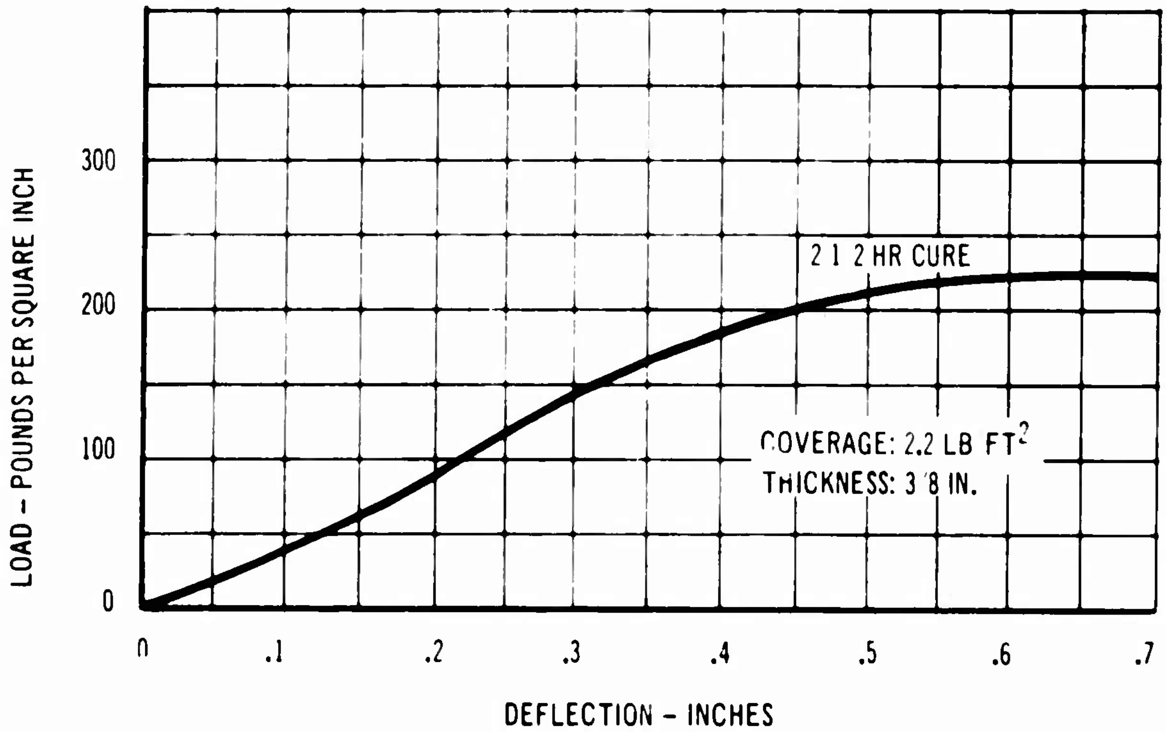


Fig. B-28 Structural and Gel Time Characteristics (Specimen No. 53)



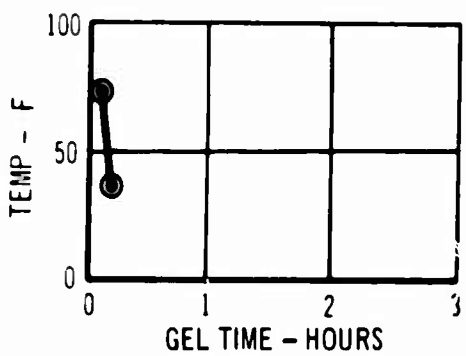
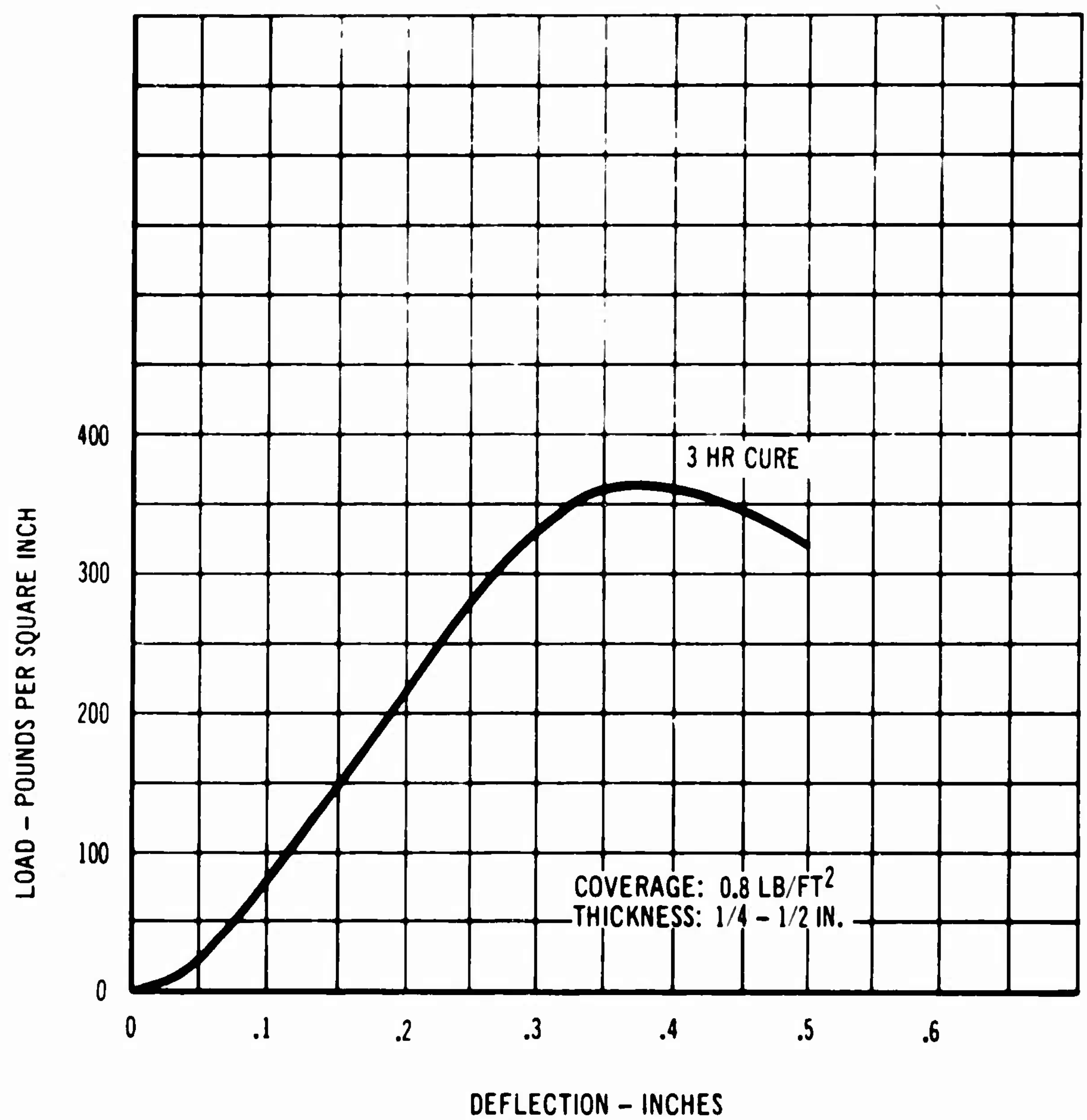


Fig. B-29 Structural and Gel Time Characteristics (Specimen No. 54)



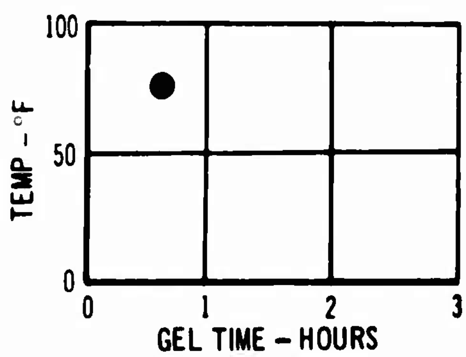


Fig. B-30 Structural and Gel Time Characteristics (Specimen No. 63)

APPENDIX C

POLYESTER SHELF LIFE

Shelf life of polyester resins is affected by the original compounding and by the nature and amount of additives. As a general rule, resins prepared for minimum gel time have reduced shelf life. Data for several specimens are given in Fig. C-1. These typical curves indicate that special provisions for storage are necessary under high-temperature conditions. It should be noted that the data used for these curves is based on the manufacturers' guarantees for presently available material. Improvements in shelf life are anticipated for materials compounded specifically for military use.

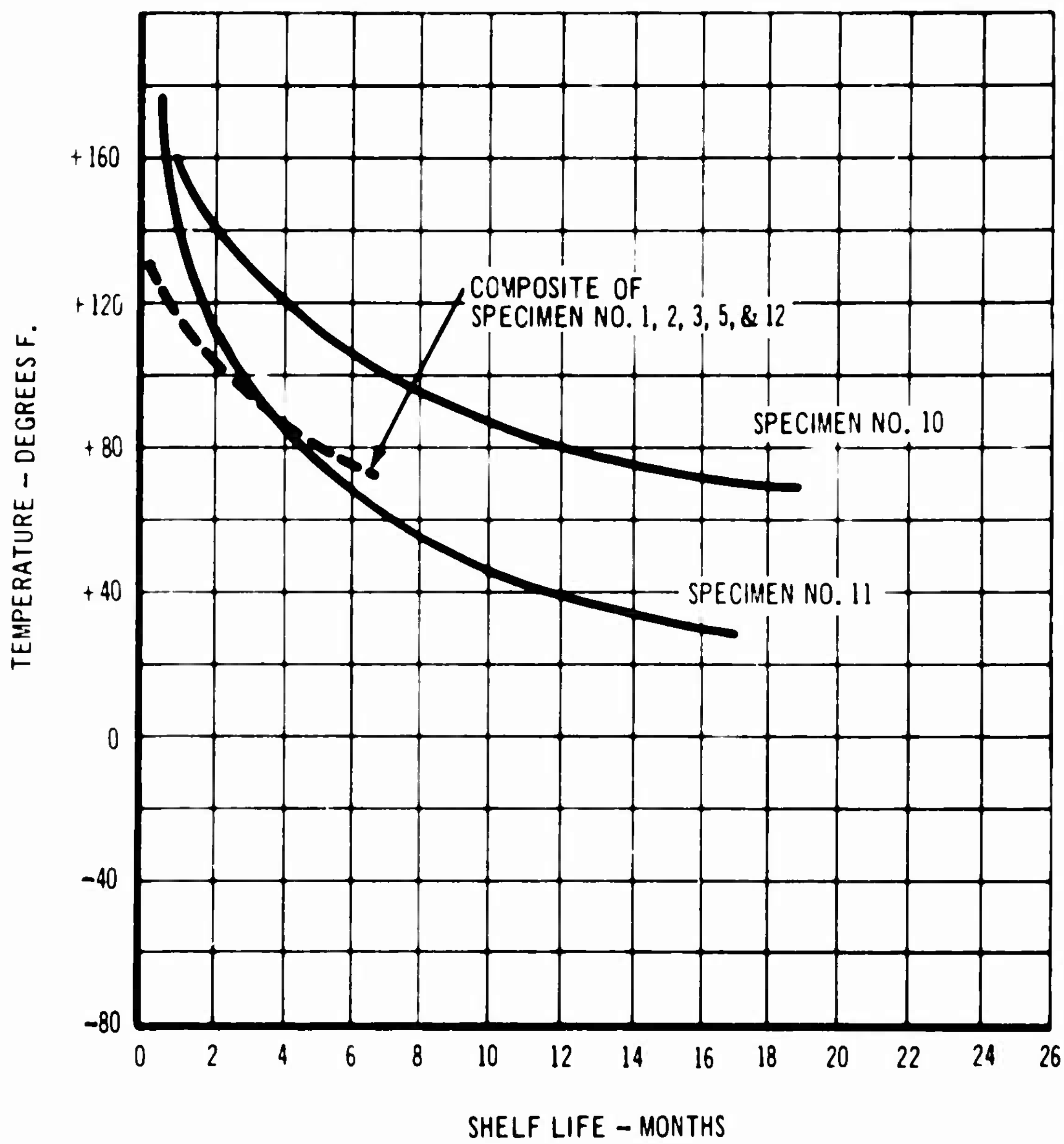


Fig. C-1 Shelf Life of Polyester Resins